# ENQUIRY INTO SEWAGE PUMP STATION PROBLEMS WITH SPECIFIC FOCUS ON REMOVING SOLIDS

By Joubert Tulleken

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**Supervisor: Prof HE Jacobs**

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# *Declaration*

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# *Abstract*

There is a general lack of published research on sewage pump station problems and the removal of solids in South African sanitary sewers. Research was undertaken to investigate the problems at sewage pump stations by means of site visits, interviews, literature reviews and laboratory experiments. An in-depth literature study is presented on sewage pump stations, pump station problems and solids in sewers. The problems at sewage pump stations were categorised into identifiable groups with possible generalised solutions. The site visits and literature review indicated a specific lack of knowledge regarding screening baskets used to remove solids at sewage pumping stations. This led to the experimental testing of a screening basket on full scale in a controlled environment to develop an efficiency index for screening baskets. The efficiency index was determined using fuzzy logic methodology with predetermined solids load, basket height above the sump level and solids retention time. The fuzzy logic proved that the basket is best operated halfway submerged, after one hour retention time and with degradable solids in the system. The literature compiled and problems identified in this study were used as the backbone for the development of a conceptual Decision Support Tool (DST) for sewage pump stations. The DST is aimed at requiring limited inputs and providing maximum knowledge output and is presented as a software tool in MS Excel format. The functionality was added by applying visual basic applications in MS Excel user forms. The idea of developing a DST is to assist designers, sewage service providers and operators with understanding the various components and for problem identification pertaining to sewage pump stations in the future. The DST is relatively self-explanatory with a user friendly visual interface that is easy to operate. This study sets the scene for further research into efficiency indices pertaining to different components of sewage pump stations and their application in comprehensive sewage pump decision support tools.

# *Opsomming*

Daar is 'n algemene gebrek aan gepubliseerde navorsing oor probleme met rioolpompstasies en die verwydering van ongewenste voorwerpe in Suid-Afrikaanse sanitêre rioolsisteme. Navorsing is gedoen om die probleme by rioolpompstasies te ondersoek deur middel van terreinbesoeke, onderhoude, literatuurstudie en eksperimente in ‘n laboratorium. 'n Omvattende literatuurstudie is op rioolpompstasies, probleme by pompstasies en ongewenste voorwerpe in rioolnetwerke gedoen. Die probleme by rioolpompstasies is verdeel in identifiseerbare groepe met moontlike oplossings. Die terreinbesoeke en literatuuroorsig het 'n spesifieke gebrek aan kennis met betrekking tot skermmandjies, wat gebruik word om ongewenste voorwerpe by rioolpompstasies te verwyder, aangedui. Dit het gelei tot die eksperimentele toetsing van 'n skermmandjie deur die volskaalse opstelling in 'n beheerde omgewing om 'n doeltreffendheidsindeks vir skermmandjies in die praktyk te ontwikkel. Die doeltreffendheidsindeks is bepaal deur gebruik te maak van “fuzzy logic” metodologie met voorafbepaalde insette naamlik, die mandjie se hoogte bo die watervlak, soort ongewenste voorwerpe en die tyd wat die voorwerpe aan water blootgestel is. Die “fuzzy logic” bewys dat die mandjie die beste werking toon, halfpad onder die water, na ‘n een uur van blootstelling aan water en met degradeerbare voorwerpe in die stelsel. Die literatuur wat saamgestel is en probleme wat in hierdie studie geïdentifiseer is, is gebruik as die inhoud vir die konseptuele “Decision Support Program” (DST) vir rioolpompstasies. Die DST het ten doel om met beperkte insette die maksimum kennis te verskaf en word aangebied as 'n sagteware instrument in MS Excel formaat. Die funksionaliteit is bygevoeg deur die toepassing van die “visual basic applications” in MS Excel gebruikersvorms. Die doel van die ontwikkeling van 'n DST is om ontwerpers, riooldiensverskaffers en operateurs te help om die verskillende funksies en probleem-identifikasie met betrekking tot rioolpompstasies te begryp. Die DST is relatief selfverduidelikend met 'n gebruikers vriendelike visuele koppelvlak wat maklik is om te bedryf. Hierdie studie bied die basis vir verdere ondersoek na die doeltreffendheidsindekse met betrekking tot die verskillende komponente van rioolpompstasies en die toepassing daarvan in omvattende rioolpomp “DSTs”.

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I am extremely grateful to all the Western Cape Municipalities for allowing me to interview their staff and accompany them on site visits.

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# *Glossary*

| | |
|---|---|
| BEP | Best Efficiency Point |
| CCP | Critical Control Point |
| CFD | Computational Fluid Dynamics |
| CSIR | Council of Scientific and Industrial Research |
| CSO | Combined Sewer Overflow |
| CSS | Combined Sewer System |
| DST | Decision Support Tool |
| FOG | Fats Oils and Grease |
| $NPSH_A$ | Net Positive Suction Head Available |
| $NPSH_R$ | Net Positive Suction Head Required |
| SAICE | South African Institution of Civil Engineering |
| SG | Specific Gravity |
| SHD | Solids Handling Device |
| SRS | Solids Removal System |
| SSO | Sanitary Sewer Overflow |
| SSS | Separate Sewer System |
| UDD | Urine Diversion Dry |
| WRC | Water Research Commission |
| WWTP | Wastewater Treatment Plant |

# 1. Introduction

Sanitation is an important part of our daily lives. South Africa has a major backlog in the provision and maintenance of sanitation systems (Lawless, 2007). According the SAICE (South African Institution of Civil Engineering) infrastructure report card for South Africa 2011 the sanitation in major urban areas is only just satisfactory for the time being and it is really unfit for the purpose in all other areas in South Africa (SAICE, 2011). This is just an indication of the major problem at hand. Sanitation and sewage systems in South Africa are in need of improvement and major upgrades. Sewer networks form an important part of sanitation and sewage treatment systems. The pump stations in sanitary sewer networks are the main focus of this study.

## 1.1 Background

Sewer systems usually operate under power of gravity, with all fluids flowing down to the lowest point. Usually, at this lowest point the sewage is treated at the wastewater treatment plant (WWTP). However, sometimes sewage reaches a point where it is unable to flow by gravity to the WWTP and this is where pump stations are required. Gravity is the most reliable option for conveying sewage and pumps could be considered as a necessary evil in sewer systems. The main reason for using pumps in wastewater treatment is to transfer wastewater from a lower to a higher level (Metcalf & Eddy, 1981). The focus of this study is on pump stations used in the piped sewer systems to help transfer the sewage to the WWTP. The major problem is to find the most appropriate pump for the water demand under specific pressure head requirements (Moreno et al., 2009).

South Africa uses separate sewer systems, where sanitary sewers are used to convey sewage and stormwater in separate piped systems. Cape Town is the city in South Africa with the most sewage pumping stations, with a total of 376 sewage pump stations, followed by Durban with 265 and then Port Elizabeth and Johannesburg (Winter, 2011). The Western Cape also has the second most WWTPs with 164 plants, after Kwazulu Natal which has 196 plants. The focus area of the investigations conducted for this study was the Western Cape.

Population growth and environmental concerns impose increasing demand for pumping sewage. Pump stations have many challenges and hazards to overcome. This is a very important field and one that is often neglected by municipalities.

Pump stations are very sensitive when it comes to the handling of solids. This report will address the problems pump stations have to deal with on a daily basis. A detailed study is presented on the solids in sewers. Although sewage consists of approximately 98% water, sewage pumps must be able to pump unpredictable volumes of grit, rags and even plastics (Rayner, 1995). Sewage pumps must handle all of these objects and pump station operators consider the cleaning of these stations as an occupational hazard (Elsevier, 1999).

## *1.2 Objectives*

The following are the three main objectives of this research:

- Identify and categorise problems that occur at sewage pump stations.
- Test the efficiency of a screening basket used to remove solids in the laboratory.
- Propose a concept DST (decision support tool) design for sewage pump stations.

Problems at sewage pump stations were identified by means of site visits, interviews and literature study. Site visits revealed a general lack of knowledge on screening baskets used to remove solids prior to pumping. This lack of knowledge and limited literature on screening baskets led to the experimental testing of a screening basket on full scale in a laboratory experiment. The proposed framework of the DST is presented as a possible solution for identifying sewage pump station problems and to aid with design guidance in the future.

All additional objectives were minor objectives identified during the period of the research. The research evolved during the period of the study and the main objectives were be achieved by starting small and successively adding complexity to the research.

### *1.3 Thesis approach*

This study had four contributing factors, namely:

- Literature study
- Site visits and interviews
- Full size laboratory experiment
- Prototype design of DST for pump stations.

There are many problems and concerns when it comes to the pumping of sewage. However, in South Africa there are no guidelines addressing these pumping problems. The lack of published articles in this field has lead to the compiling of this study. This study sets out to identify the causes of sanitary sewage pump station problems and possible solutions. The literature review is focused on pump stations to get a better understanding of how they operate and function. The literature addresses the different sectors and components of pump stations.

After the literature review was completed, site visits were conducted to gain knowledge of how pump stations operate in the field. Interviews with operators, engineers and manufacturers helped to gain a better understanding of where there is a lack of knowledge. The idea of the site visits was to establish what problems occur most often. Site visits were only conducted in the Western Cape to get a sense of what is used in practice. Some municipalities do remove solids at their pump stations and others prefer to remove all solids at the WWTP. There is big debate surrounding this concept. In this study solids removal technology at pump stations is investigated and tested to get a better perspective. These visits revealed that the two biggest problems were the handling of solids and maintenance issues. The obvious solution is to get rid of all sewage pump stations, this way there will be no problems, but that is not necessarily the most economical or the best solution in many cases (Jacobs et al., 2011). Solids handling pumps are available, but in this study the focus is on the potential threat and damage that solids may cause at sewage pump stations.

With the knowledge gained through the site visits and interviews, another literature study was done, with specific focus on the solids in sewers. This literature review focuses on what types of solids are found in sewers and the technologies that are available for removing them.

This research addresses sewage pump stations and related problems in the sewage collection system. There are no categories for labelling problems that occur at pumping stations. This study provides an index to identify and categorise the problems with pumping stations.

A full size model was designed to test a basket used to remove solids at pump stations. The screening basket was tested to get data on how it operates and the problems that may arise. The problem products tested were mainly household products, where the water closet was the main entry point.

A concept decision support tool (DST) was developed to help in selecting the appropriate parts of a pump station and to identify possible problems. The aim of the DST developed is to convey knowledge regarding pump problems to those who might need information on technologies used at sewage pump stations, and to flag potential problems to the user at an early stage, given certain inputs. The idea is to develop the framework for a tool that can act as an aid or guideline to sewage pump station designers and operators in the future. The tool could also be applied to better understand and analyse problems experienced at existing pump station locations in the future.

## *1.4 Definitions*

The key definitions are listed below:

| | |
|---|---|
| Gross solids | Gross solids are sewage-derived materials larger than 6mm (Gouda et al., 2003). |
| Pump station | Wherever a pump station is referred to in the text this refers to a sewage pump station in a sewer network, unless stated otherwise. |
| Sanitary sewer | A sewer that carries liquid and waterborne wastes from residences, commercial buildings, industrial plants and institutions, together with minor quantities of ground, storm and surface water which are not admitted intentionally (Water Environment Federation, 2008). |

| | |
|---|---|
| Screen | A device with openings, generally of uniform size, used to remove suspended or floating solids in a flow stream, thus preventing them from passing a given point in conduit. |
| Screening | Screening is interpreted to mean not only the physical removal of screenings from the crude sewage, but also their side-stream or in-flow disintegration (Sidwick, 1984). |
| Screening basket | A basket used at pump stations to catch or remove solids from sewers prior to pumping. |
| Screening removal system | SRS is a device or system used in a sewer system, usually at sewage pump stations to remove or reduce screenings from the sewage system. |
| Screenings | Screenings are typically removed by bar screens or bar racks. These are relatively large debris consisting of rags, plastic, cans, rocks and similar items (Water Environment Federation, 2008). |
| Sewage | Sewage is waste and excrement which is disposed and conveyed in sewers. |
| Solids | For the purpose of these study solids are defined as the constituents in sewers that are not supposed to be in sewers and therefore have to be removed. |

# 2. Literature

Wastewater reticulation involves the use of multifarious pipeline networks and pumping stations to direct and transport sewage to the treatment facilities (Winter, 2011). Along sewer pipelines there are critical control points (CCP). A CCP is a place along a wastewater collection and treatment system where there is access to the system to do monitoring or interventions that can have an effect on the water quality (van der Merwe-Botha & Manus, 2011). A pump station is the most important CCP in a sewer system. Pump stations very often go unnoticed by the public, but they are an imperative contributor in the basic sanitation system. South Africa produces approximately 5800M*l* of wastewater per day, all of which is probably pumped somewhere along its journey through the sewer system. Pump stations are the most critical elements in ensuring that a wastewater distribution network operates smoothly (Winter, 2011). This chapter focuses on the design, operation and maintenance phases of the pump station life cycle. The construction phase is addressed briefly in some sections. Pump stations are in some cases complicated systems comprising many parts and sections. All these sections are addressed in a thorough literature study in this chapter. This chapter also presents many visual aids, which will be used for a Decision Support Tool (DST) addressed in Chapter 6.

## 2.1 Pump station basics

In order to simplify the understanding of sewage pump stations, this question is addressed throughout this report with the help of the following categories as presented in Figure 2.1:

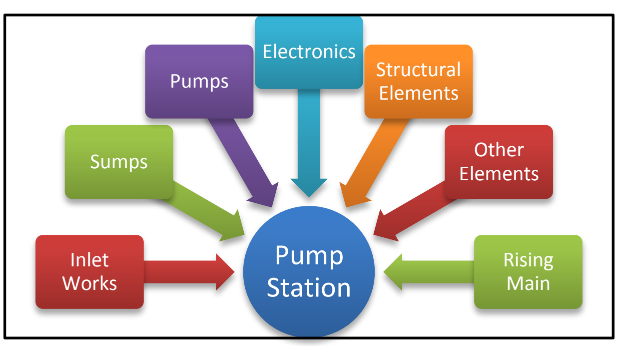



**Figure 2.1. Pump station categories**

These categories are presented in section 2.2 to section 2.8. The rising main is not addressed in detail in this study. The pump station components can be seen in Figure 2.2.

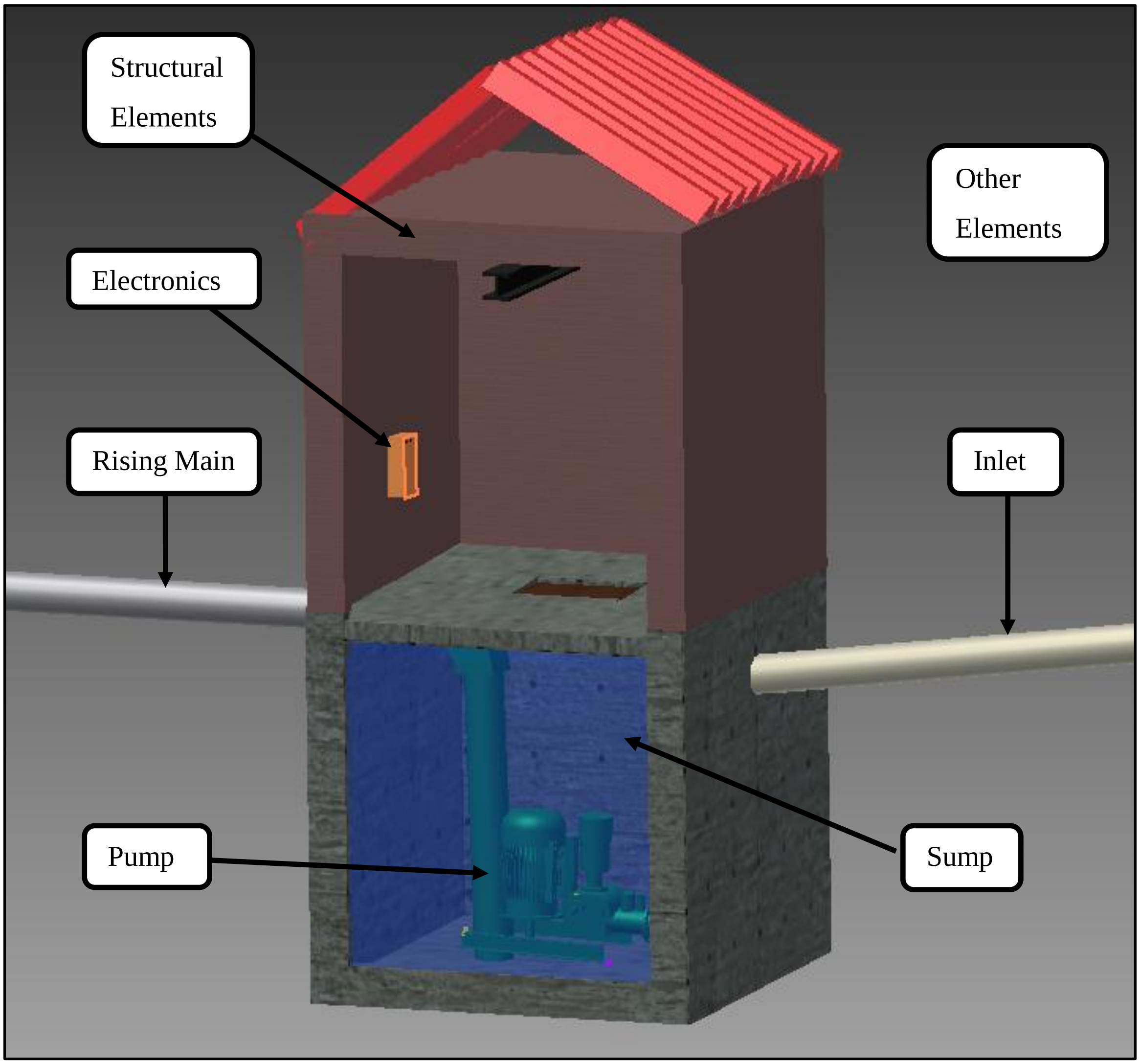



**Figure 2.2. Pump station basic components**

Pump stations can be located anywhere from housing areas to sensitive environmentally areas, usually at the lowest point in the area. If problems occur, raw sewage could flow into these sensitive areas and have a permanently damaging effect. That is why it is of great importance that pump stations work efficiently. Figure 2.3 presents a number of different pump stations.

**Figure 2.3. Different pump stations**

Liquids flow from a higher point to the lowest point, which is where a pump station will be situated. Sewage travels by means of a pipe or channel which is called the inlet. The inlet carries the sewage into the sump; the sump is a temporary housing unit for the sewage until it is pumped away. The sewage is then pumped from the sump via the rising main to the next point of interest, which could be the WWTP or a point from where the water can travel under gravitation to its next point of interest.

## *2.2 Inlet Works or Preliminary Treatment*

The inlet or preliminary treatment section consists of a pipe or channel conveying the sewage to the sump. The inlet works is the pump station's primary defence and therefore it can have a great impact on how the pump station functions. The inlet works are addressed in more detail in Chapter 3 of this report. The inlet can be just a pipe conveying sewage directly into the sump or it can include structures designed to remove solids. Some pump stations have no primary treatment, but in cases where there is treatment it normally consists of screening and grit removal.

### 2.2.1 Screening

"*Screening is interpreted to mean not only the physical removal of screenings from the crude sewage but also their side-stream or in-flow disintegration*" (Sidwick, 1984).

Screening can be done with the help of screens and screening baskets to remove the larger solids and unwanted objects. Screening removes objects such as rags, plastics, metal and paper to prevent damage to the pump or pipes downstream (Nozaic & Freese, 2009). Screens are usually placed upstream of delicate equipment, in this case pump stations (Sutherland, 2009). Solids can be removed by coarse screens to remove gross solids and/or fine screens to remove finer solids. The implementation of screening decreases the potential for damage of sewage pumps, potentially thus increasing the lifetime of the sewage pumps.

### 2.2.2 Grit Removal

Grit normally composes of small heavy particles or course inorganic matter like sand and gravels (Water Environment Federation, 2008). Removal of grit is done with sand traps, grit chambers or degritters, all of which use sedimentation to remove the grit. Sedimentation of grit can occur in pipes and sumps if infrastructure is not well constructed. The ideal is to keep the grit moving in sewer networks and then to remove it from the system at pump stations or WWTPs. The nature and behaviour of grit in sewers is still relatively unknown.

## *2.3 Sumps*

A sump is a well where the sewage accumulates in order that it can be pumped away. Sumps are usually below ground level. Different designs and construction techniques for sumps are used in pump stations. According to the *Guidelines for Human Settlement Planning and Design* a sump should allow for 4 hours of emergency storage at average flow rate of a station serving less than 250 dwellings (CSIR, 2003).

Pumping stations can consist of many wells. The dry well is generally where the pump, motor and electronic components are situated. The wet well is where the sewage is located. There are various combinations of the wet and dry wells (Pollard, 2009).

### 2.3.1 Wet and Dry well (Conventional dry well)

The conventional dry well pumping station comprises two underground wells. One well houses the pump and the other is the catchment for the sewage. This type of arrangement is usually found at large pumping stations, where maintenance needs to be a simple operation. It is also found at old pump stations. The pump pumps the liquid from the wet well to a higher location, as seen in Figure 2.4.

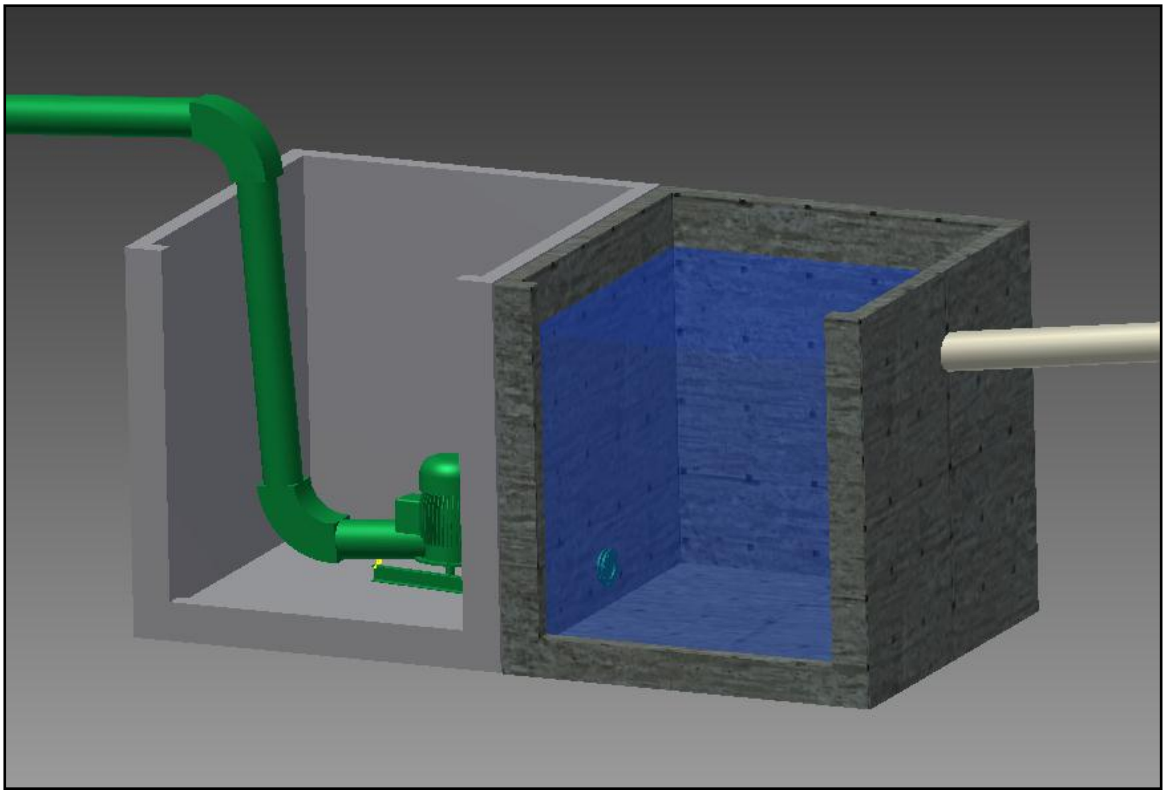
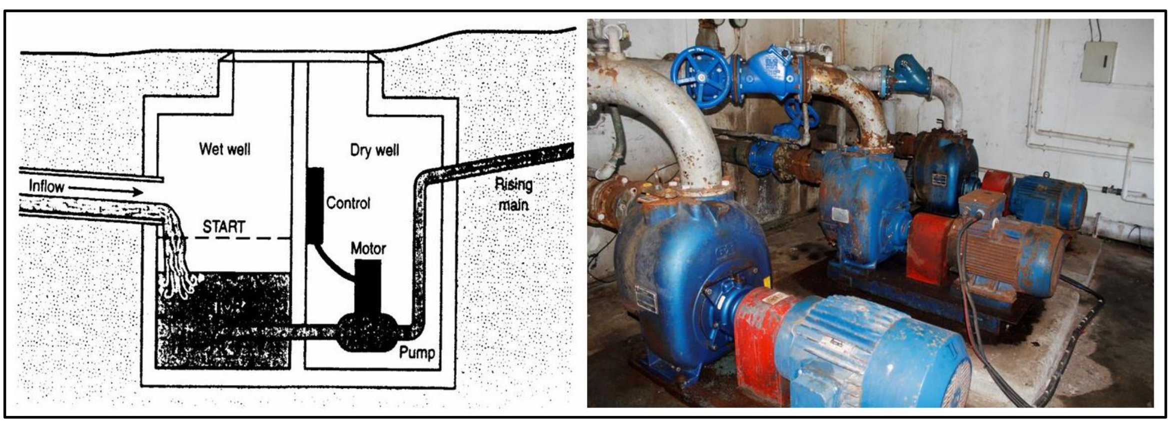


**Figure 2.4. Conventional dry well**

Figure 2.5 presents an ideal illustration of a conventional pump station on the left and the dry well of an Hermanus pump station on the right. The pumps used for this type of installation are referred to as immersible pumps.




*Ideal installation (Stephenson & Barta, 2005)

**Figure 2.5. Installation of conventional dry well pump station**

### 2.3.2 Wet well (Self priming pumps)

This station has an underground well and a housing unit at ground level. A self priming pump is used to lift the sewage from the wet well. In this layout the pump does not have to be at the same level as the incoming wastewater, as can be seen in Figure 2.6.

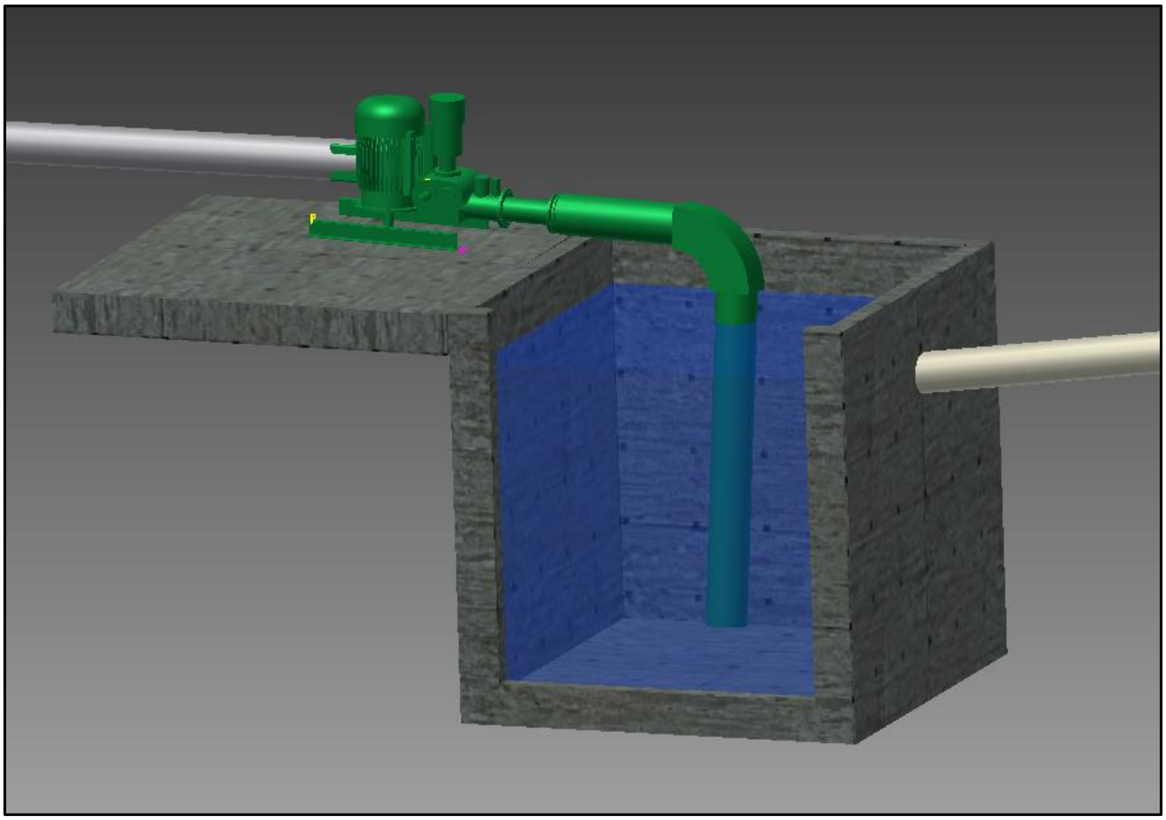


**Figure 2.6. Self priming pump installation**

### 2.3.3 Wet well (Submersible pumps)

This station has one underground wet well, where the pump is located. Most of the smaller pump stations do not have a house or structure over the well. It is covered only by a cast-iron manhole cover. The pump is fully submerged as depicted in Figure 2.7.

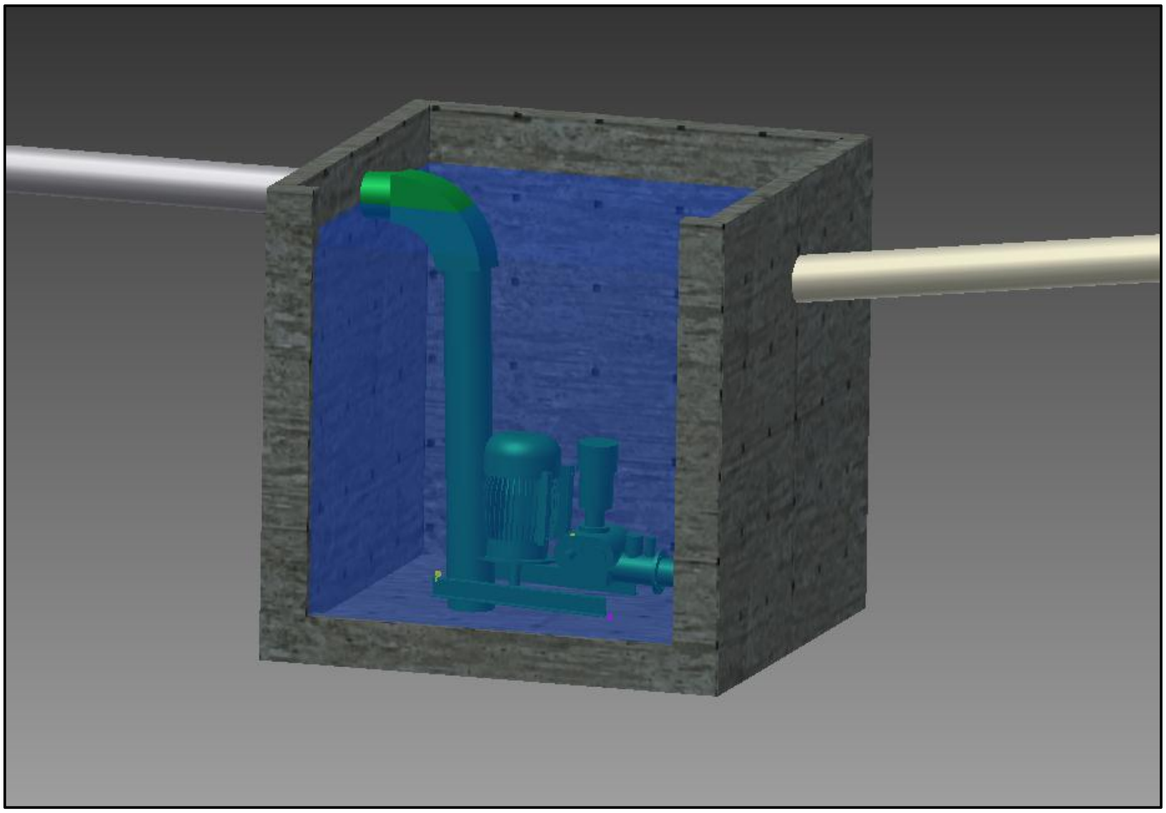


**Figure 2.7. Submersible pump installation**

Conventional dry well pump stations used to be the norm and are still used. Modern requirements for wastewater pumps include the following (Berezin, 2006):

- Reliability and continuity of service, including in cases of emergency
- Removal of the need for operating staff
- Elimination of emergency output
- Noise minimisation
- Prevention of unauthorized entry
- Adaptability to flow fluctuation
- High energy efficiency.

It is not possible to meet all these requirements, but centrifugal submersible pumps are the most suitable, because submersible pumps are preferred for new pumping stations and for the upgrading of old stations (Berezin, 2006). The advantage of submersible pumps is that they don't need a housing unit, because they are submerged under the liquid in the sump.

## *2.4 Pumps*

Pumps used for lifting sewage are usually high capacity, low head installations with low flow and large openings capable of passing solid materials (Bowers, 1973). This does not mean that pumps used at sewage pump stations can handle all solids present in sewers. The solids in sewers pose many threats to all pumps used in sewers. Figures of pumps and different pump installations are presented in Appendix A.

### 2.4.1 Pump types

#### *2.4.1.1 Classification*

Hydraulic machines (pumps) can be divided into continuous flow (kinetic or dynamic) units and positive displacement units (Chadwick et al., 2004). The focus of this study will be on continuous flow units, which are used in sewage pump stations.

In general, the three classifications for kinetic pumps are radial flow, mixed-flow and axial flow. Radial-flow pumps are used mostly for pumping sewage and storm water (Metcalf & Eddy, 1981). Various radial-flow pumps are available and they can be classified as centrifugal pumps. Most of the pumps in sewer systems are centrifugal pumps (Pollard, 2009).

#### *2.4.1.2 Specific speed*

In order to determine what type of pump should be used the specific speed of the impeller is required. The specific speed is the number that defines what pump should be used (Chadwick et al., 2004; Finnemore & Franzini, 2009):

$$N_s = \frac{N\sqrt{Q}}{{H_p}^{3/4}} \qquad \text{....1}$$

Where

$N_s$ = pump specific speed

N = Rotational speed (rpm)

Q = flow at optimum efficiency ($m^3$/s or l/s)

$H_p$ = total head (m)

For

$10 < N_s < 70$ radial flow (centrifugal) units (high head, low discharge)

$70 < N_s < 165$ mixed flow units (moderate head, moderate discharge)

$110 < N_s$ axial flow units (low head, high discharge)

### *2.4.1.3 Pump family tree*

Centrifugal pumps are widely used all over because of their smooth flow rate, high efficiency, head and range of capacity. Their simple design makes them easy to maintain and operate (Girdhar & Moniz, 2004). The family tree of pumps is presented in Figure 2.8 below.

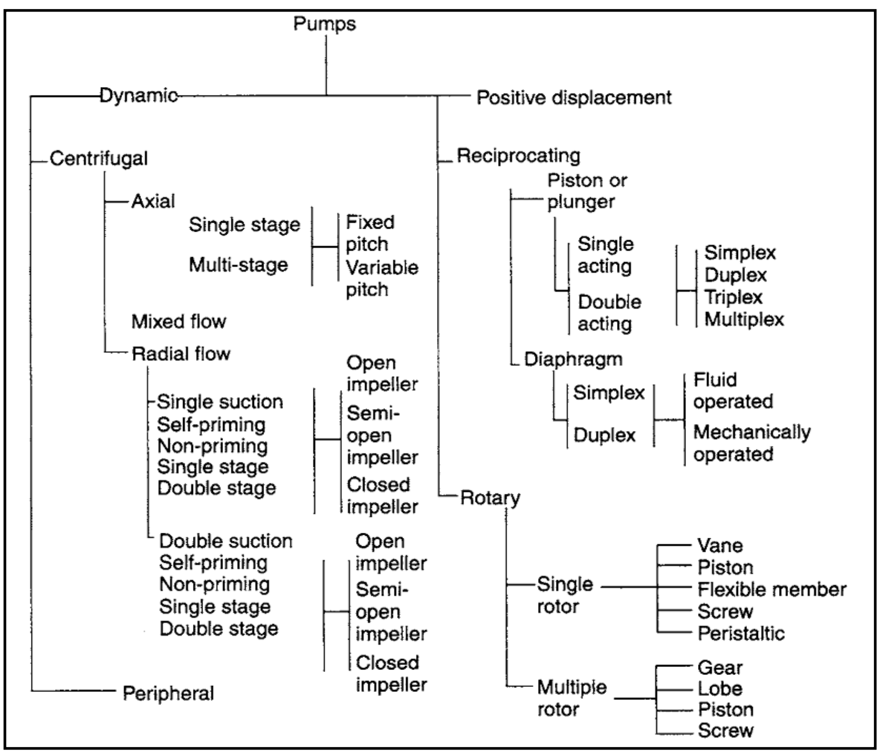



**Figure 2.8. Pumps Family Tree (Turton, 2002)**

Radial-Flow pumps are the most commonly used pumps when it comes to wastewater pumping. These pumps have the ability to pump liquids and they can handle fluids with various properties (Chadwick et al., 2004). A centrifugal pump consists of two main parts; a rotating element which is called the impeller, and the casing enclosing the impeller, as illustrated in Figure 2.9.

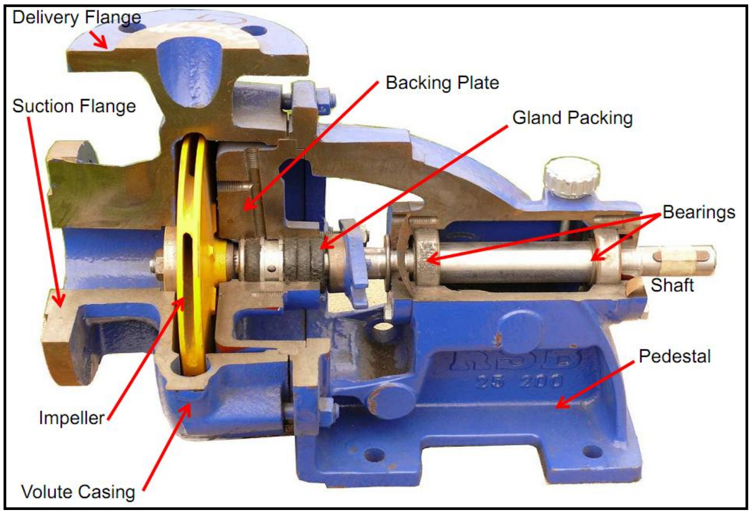



**Figure 2.9. Pump casing and components (Van Dijk, 2010)**

### *2.4.1.4 General features*

A few general features of centrifugal pumps which should be kept in mind are presented in Table 2.1 (Van Dijk, 2010).

**Table 2.1. Advantages and disadvantages of centrifugal pumps**

| Advantages | Disadvantages |
|---|---|
| Low cost | Variable capacity |
| Low Maintenance | Low discharge |
| Steady Flow | Serious restrictions on the suction side |
| Flow control by trotting | Priming usually required (if not submersible) |
| For same capacities, units are smaller than positive displacement types | |

#### *2.4.1.5 Solids handling ability*

Pumps with solids handling ability present a technology that makes a significant contribution to enhancing the operational reliability and reducing the costs of manpower and electrical consumption of sewage pump stations. It introduces the concept of a self-cleaning submersible pump station that is achieved by the installation of special sump geometry which results in all settled and floating solids, greases and fats being removed every pumping cycle. A benefit of such a system is that man entry into a sewage wet well is eliminated, as is the need to deploy a vacuum tanker and its attendant crew delivering a significant cost saving to the user (Jacobs et al., 2011).

In the case of solids handling pumping it is necessary to provide passage ways through which entrained solids can pass. Although the basic principles still apply, it becomes necessary to alter impeller design accordingly. Standard water impellers with double shrouds and multiple vanes provided a solution, but are in many cases no longer suitable particularly when handling fibrous materials.

The screw centrifugal impeller has been developed with special geometry that ensures that material which accumulates on the inlet edge of the single blade is swept clean automatically. Rags and fibres which contact the blade leading edge are swept to the centre of the impeller where they are deposited into the flow and pass freely through the pump, as illustrated in Figure 2.10.

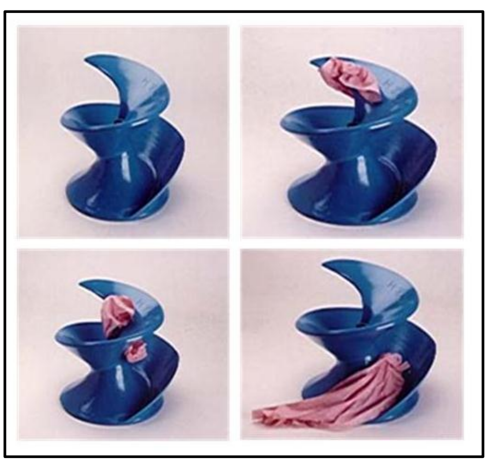


**Figure 2.10. Screw centrifugal impeller passing a rag (Worthington-Smith, 2011)**

### 2.4.2 Pump selection

Problems at sewage pumps may originate from improper design. For this reason it was considered appropriate to add the basic theory of pump selection to this report. In order to select a pump for a specific system the following need to be known:

- Pump characteristics
- Pump efficiency
- System characteristics.

#### *2.4.2.1 Pump characteristics*

Every pumping system has specific needs and therefore it is important to select the correct pump for it. Pumps are identified by their efficiency curves, performance curves (pump curves) and net positive suction head (NPSH) requirements. The pump curves are normally supplied by the pump manufacturers, with varying conditions being given on the same graph. The curve gives relational information on variable speed, flow, pressure, efficiency, absorbed power and $NPSH_R$.

The required $NPSH_R$ is the minimum head needed to avoid cavitation. The available $NPSH_A$ is calculated as follows (Water Environment Federation, 2008):

$$NPSH_A = \frac{P_{atm} - P_{vp}}{\gamma} + Z_w - H_L \qquad ....2$$

Where

$P_{atm}$ = the absolute atmospheric pressure exerted on the free fluid surface on the suction side of the pump (atmosphere pressure, based on height above sea level)

$P_{vp}$ = the fluid's vapour pressure (based on fluid temperature at suction)

$Z_w$ = vertical distance between fluid surface and pump centreline

$H_L$ = the sum of all the head losses in the suction piping

To avoid cavitation the following always has to be true:

$$NPSH_A > NPSH_R \qquad ....3$$

### *2.4.2.2 Pump efficiency*

The pump's efficiency (η) is the difference between the brake power ($P_b$) input and the water power ($P_w$) output (Finnemore & Franzini, 2009; Water Environment Federation, 2008).

$$\eta = \frac{\text{output power}}{\text{input power}} = \frac{P_w}{P_b} \qquad ....4$$

Where

Water power ($P_w$) is the energy needed to pump fluid from one location to another

Brake power ($P_b$) is the energy provided to the pump by the motor

### *2.4.2.3 System characteristics*

The system characteristics for a single pipeline between two points can be calculated by the following (Haested et al., 2004):

$$H = h_1 + \sum K_p Q^z + \sum K_M Q^2 \qquad ....5$$

Where

H = total head (m)

$H_1$ = static lift (m)

$K_p$ = pipe head loss coefficient ($s^z/m^{3z-1}$)

Q = pipe discharge ($m^3/s$)

Z = coefficient

$K_M$ = minor head loss coefficient ($s^2/m^5$)

The system characteristic curve can change if valves upstream from the station are closed, or with the altering level in the sump.

The system operating point, the intersection of the pump performance curve and the system head curve at a specific speed, is as illustrated in Figure 2.11. The idea is to get the operating point as close as possible to the best efficiency point (BEP). The BEP is the point on the pump curve where the pump operates at its maximum efficiency (Water Environment Federation, 2008).

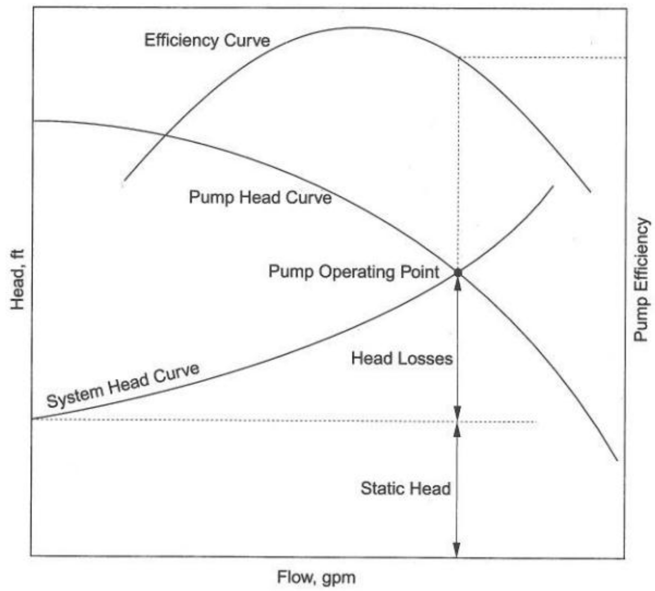



**Figure 2.11. Definition of the operating point (Haested et al., 2004: 127)**

Pumps in series allow for more head and pumps in parallel for more flow, as illustrated by the pump curves in Figure 2.12.

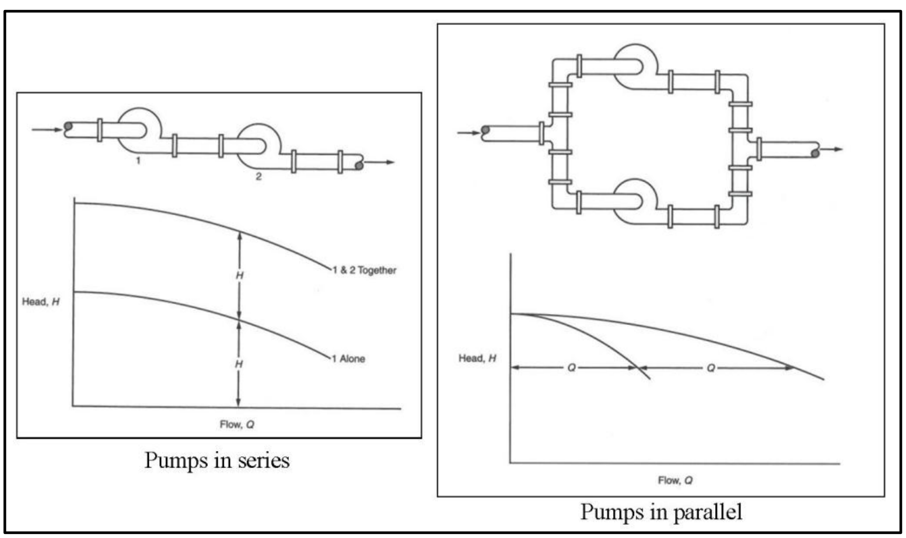



**Figure 2.12. Pumps in series and parallel (Vesilind, 2003: 324)**

When all the characteristics and properties of an application have been addressed the most suitable pump can be selected. However, it is not always possible to select the perfect pump and it is often necessary to select a pump not complying with the ideal properties. The choice of pump must be made according to the specific requirements of the case in question. Sometimes there has to be a compromise with regard to the technical features of the pump and, although not ideal, this is very common (Nesbitt, 2006).

It is necessary to collect all the information possible when it comes to pump selection. With the correct information the most suitable pump can be selected and time and money will be saved. With the initial selection of any pump certain factors need to be known.

For a pump application, other properties of the station can play a vital role and it is important to keep them in mind when selecting a pump for a specific installation. The following are other properties that can be crucial when selecting a pump (Nesbitt, 2006; Larralde & Ocampo, 2010):

- Temperature of the liquid
- Viscosity of the liquid
- Constituents in the liquid
- Properties of the liquid
- Power
- Controls
- Odour control
- Available space and access.

### 2.4.3 Back-up pumps

It is recommended that all pump stations should have at least one back-up or stand-by pump (Jones, 2006; CSIR, 2003). Usually pumps operate in support of one another. While one pump is pumping, the other is the back-up, and they alternate every six hours. The picture in Figure 2.13 shows a self priming pump on the right and a back-up portable pump on the left at Scottsdene pump station.

**Figure 2.13. Pumps at Scottsdene (Western Cape) pump station**

## *2.5 Electronics*

Energy usage in the water and wastewater treatment sector is dominated by pumping activities. Pumping consumes the greatest portion of energy, followed by telemetry equipment in the distribution networks. (Winter, 2011).

### 2.5.1 Telemetry and control systems

Telemetry systems make use of SMS or radio-telemetry to transfer data from the pump stations to the operators. Telemetry systems should be capable of transmitting information to and from the pump station's controls and signals (van Vuuren & van Dijk, 2011). Telemetry systems are essential to unmanned pump stations.

Control boxes, panels or rooms are there to help operators manage the pumps of the pump station. These control boxes also serve as an alarm system if something should go wrong. Alarm systems should be linked up with the telemetry system in order to inform operators of problems at any time of the day. Small stations have control boxes with only the options of switching the pump on or off. Some large pump stations have elaborate systems with computers logging all the data of the station. Anything from sump levels, pump speed, pump efficiency, generators, valves, cranes, odour control and switching between pumps can be adjusted by means of varying control options. Figure 2.14 below illustrates various control facilities.

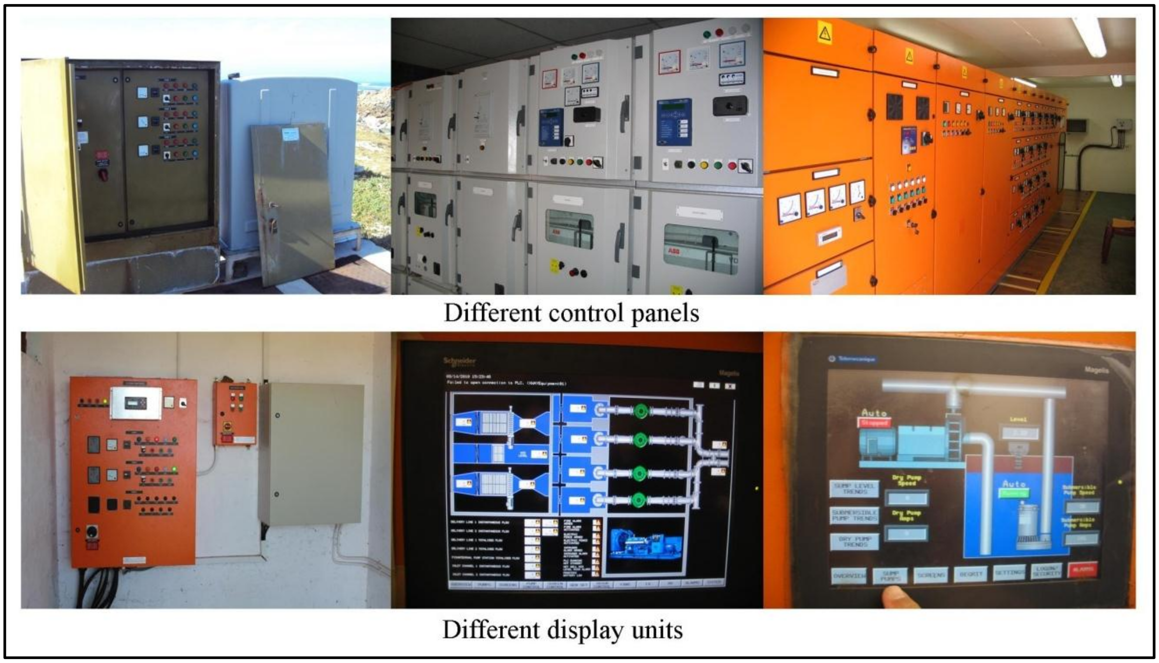



**Figure 2.14. Control boxes**

### 2.5.2 Level meters and wiring

Level meters are used to measure the surface level of the wastewater in the sump. Level meters come in the form of level probes or ultrasonic level meters, as presented in Figure 2.15. They are essential parts of the pump stations and are used to control the runtime of the pumps. The meters automatically switch the pumps on and off, depending on the level of the wastewater. This is done to protect the pumps from burning out and to control the quantity of sewage in the sump.

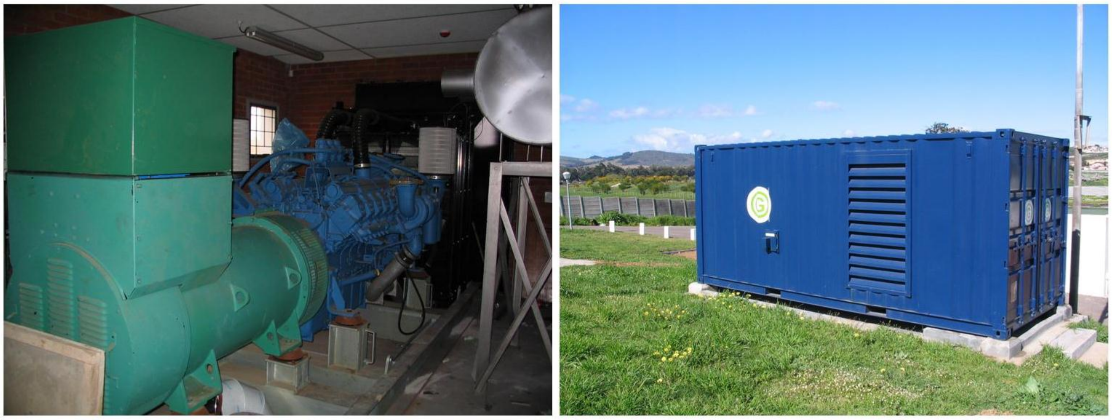
Wiring is the connection between the control boxes and the pump. This transmits both the power and instructions from control panels to the pump. It is vital that the wiring is correctly installed. During maintenance and pump services the wiring should be placed back correctly, especially with submersible pumps, where the wiring goes all the way down in the sump (Trautmann, 2010).

Ultrasonic level meter　　Wiring to submersible pump

**Figure 2.15. Level meter and wiring**

### 2.5.3 Power failure

Generators are used when a power failure occurs. Generators are normally powered by a diesel engine and start working as soon as the electrical power fails. Generators need to be tested on a regular basis to ensure that they are in working order if a power failure should occur. Portable or mobile generators are often used in small towns where capital is limited. These portable generators often serve as a back-up for many pump stations. Figure 2.16 presents a generator and a housing unit for a generator.



Generator Generator housing unit

**Figure 2.16. Generator and housing unit**

## *2.6 Structural Elements*

Structural elements are systems not crucial to the working of a pump station. However, these elements do contribute to the effective operation of the station.

### 2.6.1 Layout and Location

The correct location and layout of a pump stations can make operating the station much easier. Pump stations need the following aspects to simplify maintenance and operation:

- Housing unit
- Access roads for vehicles
- Enough space to remove pumps and do repairs

If possible, pump stations should not be situated close to sensitive natural environments. The potential of overflows should not be able to have a negative effect on the surrounding environment.

### 2.6.2 Equipment

A pump station should be equipped with the following to ensure effective operation:

- Gantry, hoisting equipment or crane for lifting pumps to ground level
- Water and electrical supply
- Fire protection equipment (fire extinguisher)
- Overflow facility (overflow pipes and dams).

Overflow dams as presented in Figure 2.17 are back-up systems for when the pumps fail or the inflow is more than the capacity of the station. Sewage can then flow out into a dam for the time it takes for the pump to be repaired or until flows decrease. Overflow dams are ideal for wet weather flows that may in extreme cases exceed the capacity of the pump station. The overflow flows into the dam and is then recycled back to the station inlet when the initial inflow subsides (Stephenson & Barta, 2005). Overflow dams should be drained and cleaned from time to time.

**Figure 2.17. Overflow dam**

## *2.7 Other Elements*

Other elements include aspects that should be kept in mind when designing a pump station. These aspects can include the following:

- Emergency response teams
- Environmental impact assessment
- Health and safety standards
- Maintenance
- Noise minimisation
- Odour control (photo presented in Appendix A)
- Security, fencing and alarm systems
- Ventilation in station.

Pump stations require high levels of maintenance. There is electrical, mechanical and control equipment that need basic maintenance and operators doing this maintenance should be trained (Butler & Davies, 2004).

The *Waterborne Sanitation Operations and Maintenance Guide* provides some guidelines for pump station maintenance and a pump station operation inspection checklist (van Vuuren & van Dijk, 2011).

A very important factor of maintenance is monitoring the performance of the pumping station. It is necessary to monitor the following (Butler & Davies, 2004):

- Failure in the electricity supply
- Pump failure
- Unusually high levels in the wet well
- Flooding of the dry well
- Operation of the overflow
- Cleaning of screens and baskets (van Vuuren & van Dijk, 2011).

## *2.8 Rising Main*

The rising main is the section between the pump station and the next point of interest, usually upstream from the pump station, but at a higher level as the pump station. For the purpose of this study the rising main is not addressed in further detail.

## *2.9 Construction*

This study does not address the construction phase of pump stations in detail; however there are certain aspects that should be kept in mind. There are necessities for construction and they are addressed throughout this report. If the construction and the preliminary research on the area are not done properly, problems might occur at the station. It is important to be proactive to avoid future problems. The following should be kept in mind during the construction phase:

- Weather
- Environmental impact
- Safety
- Local community.

# 3. Solids in Sewers

There are various technologies available for removing solids from sewers. The big debate is whether some solids should be removed at pump stations or whether all solids should be removed at the WWTP. This chapter investigates the case where solids are removed at pump stations. However, this method requires regular maintenance and that poses a new set of problems. The philosophy is to solve problems as they occur and not wait for problems to increase the intensity further downstream. This is considered to be the proactive approach. This chapter addresses the handling, removal and composition of solids at pump stations. It does not address the chemical compounds of solids found in sewers.

The author of this report and de Swart & Barta (2008) has found that the majority of literature available about solids and overflows is on Combined Sewer Systems (CSS), although South Africa has been implementing Separate Sewer Systems (SSS). This chapter addresses both SSS as well as CSS techniques where they are applicable to SSS. Figure 3.1 is an illustration of a typical SSS, with the advantages presented in Table 3.1.

FIGURE CSS

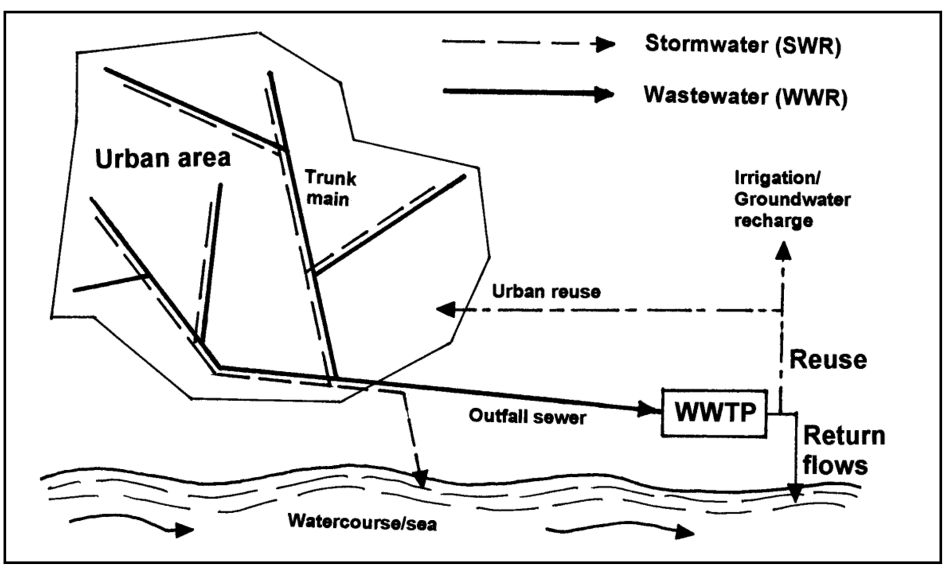



**Figure 3.1. Hypothetical layout of separate sewer system (Stephenson & Barta, 2005)**

**Table 3.1. Advantages and disadvantages of SSS (Stephenson & Barta, 2005)**

| Advantages | Disadvantages |
|---|---|
| Smaller WWTP | Extra cost of two pipes |
| Collection sewer pipe smaller, maintaining greater velocities | Additional excavation space and volumes |
| Less variation in flow and strength of wastewater | More house drains with risk of wrong connections |
| Limited surface area grit in collected wastewater | No regular flushing of wastewater deposits |
| | No treatment of stormwater |

In an ideal world pumps would be able to pump sewage without the use of screening technologies. If only the objects that are supposed to be in sewer systems were there, the use of screens would not be needed; this is unfortunately not the case. In a third world country where the majority of the people live in poverty the problem is even more prominent. Many new pump manufacturers develop pumps capable of pumping solids. Nevertheless, with the unwanted objects in South African sewers even these pumps fail at some stage. Pumps are not made to handle bricks, cans and the unwanted objects found in foul sewers. Some sort of a screening mechanism to remove the solids is therefore required before the sewage gets pumped. Pumps can only handle solids the size of their mouth opening. Preliminary treatment of sewage is needed to remove constituents such as sticks, grits, rags, floatables and grease that may cause operation and maintenance problems (Metcalf & Eddy, 2003). Screens can remove most of the solids larger than the pump can handle. There is a great need for robust systems in informal areas. Larger matter needs to be reduced to an acceptable size for the pumps. Fine screens are already in use at most WWTPs; therefore only robust systems are needed at pump stations.

Even though screening activities constitute a relatively low technological component within the greater wastewater treatment system, their importance as the primary defence against pump damage should not be underestimated.

### *3.1 Entry points*

Solids can enter the sewers at a number of places. Sanitary sewers (SS) have fewer entry points than combined sewers. In South Africa the following are places where unwanted objects can enter the sewers:

- Toilet
- Shower and bath
- Bathroom basin
- Kitchen sink
- Gulley
- Manholes
- Industrial or commercial facilities (chicken farms, restaurants, factories).

### *3.2 Flow rates*

Flow rates in sewers are dependent on factors such as time of day, time of year, weather, deposits in sewers, slime, pipe size and pipe slope, to name only a few. The various factors are listed by Ashley et al. (2004) in the list below:

- Dry weather flow rate and concentrations
- Period of the day
- Rainfall intensity and duration (infiltration)
- Antecedent dry weather period
- Amount and type of deposits in system
- Amount and growth rate of slime (slime growing inside pipes)
- Age and condition of sewer fabric (pipe corrosion)
- Sewer maintenance and cleaning practices
- Sewer geometry, size and slope.

During the wet weather season rain and storm water infiltrate the sewers. The total mass of solids can be 5 to 10 times more in wet weather than in dry weather periods (Ashley et al., 2004). The flow conditions in sewers differ according to the time of day. Peak flows normally occur during the mornings and evenings, although in certain areas the peak flows differ from the norm. Pump stations serving areas with schools, collect their peak flows during the break periods at school. Industrial facilities sometimes release their effluents during the night to avoid the daily peak flows. Table 3.2 illustrates minimum flow velocities for different countries.

**Table 3.2. Minimum velocities table (Ashley et al., 2004: 253)**

| Source | Country | Sewer Type | Minimum velocity (m/s) | Pipe Conditions |
|---|---|---|---|---|
| American Society of Civil Engineers (1970) | USA | Foul | 0.6 | Full/half full |
| British Standard BS 8001 (1987) | UK | Storm | 0.9 | Full/half full |
| | | Storm | 0.75 | Full |
| | | Combined | 1.0 | Full |
| Minister of Interior (1977) | France | Foul | 0.3 | Mean daily flow |
| | | Combined | 0.6 | For a flow equal to 1/10 of the full section flow |
| | | Separate storm sewer | 0.3 | For a flow equal to 1/100 of the full section flow |
| European Standard EN 752-4 (1997) | Europe | All Sewers | 0.7 once per day for pipes with D<300mm, 0.7 or more if necessary in sewers larger than D = 300mm | N/A |
| Abwassertechnishe Vereinigung ATV Standard A 110 (1998) (replaced by ATV 110 (2001)) | Germany | Foul<br>Storm<br>Combined | Depends on diameter of pipe ranging from 0.48 (D=150mm) to 2.03 (D=3000mm) | 0.3 to full for 0.1 to 0.3, velocity plus 10% |

In South Africa the minimum velocity is 0.7m/s for all diameter pipes (CSIR, 2003).

## *3.3 Composition of Solids in Sewers*

Due to the variety of flow regimes and operational characteristics, the behaviour of solids cannot be generalised. It is better to predict the nature of solids by local observations or measurements than to compare it with published averages (Ashley et al., 2005).

The specific gravity (SG) of solids defines where they will accumulate in a sump. Table 3.3 presents the types of solids with their SG.

**Table 3.3. Specific gravity of solids**

| Buoyancy | SG | Type of solids |
|---|---|---|
| Settling solids | SG > 1 | Inorganic such as grit, sand, silt and also rags, clothing and some heavy organic matter |
| Neutral-buoyancy Solids | SG = 1 | Most organic matter and sanitary items such as paper, plastics, string and cotton buds |
| Floating solids | SG < 1 | Fats, oils, plastics, hollow objects and light organic matter |

*Adapted from (Czarnota, 2008)

### 3.3.1 Rhone-Alpes, France case study

In a period from 2007 to 2008 a total of 30 screenings samples were collected at three WWTPs in Rhône-Alpes, France (Le Hyaric et al., 2009). The samples came from combined and partially separate sewers. Samples were taken from screens ranging from 3-60mm in size. All the samples were dried at 80$^{o}$C for a period of one week to determine their dry mass. A total of 3.6 tons wet mass of solids was collected. Le Hyaric et al. (2009) divided the findings into the categories presented in Table 3.4.

**Table 3.4. Characterization of screenings (Le Hyaric et al., 2009)**

| Screenings Fractions | Fraction components |
|---|---|
| Sanitary textiles | Tampons, sanitary towels, wipes |
| Fine fraction (<20mm) | Ash, sand, broken glass, vegetal waste and fine residues that pass the sieve |
| Vegetal | Cut Grass, herbs, flowers, twigs, branches, leaves |
| Paper, cardboard | Newspapers, packages, brown corrugated cardboard, paper rolls, office paper |
| Plastics | Plastic bags, plastic films, plastic containers, pipes, pens, toothbrushes, tubes of toothpaste, condoms |
| Textiles | Natural fibre textiles (cotton, wool, linen) and synthetic fibre textiles (tights, sport bags) |
| Metal, Aluminium | Cans, keys, tools and all ferrous and nonferrous materials |
| Composites | Packaging made of several materials (paper, plastic, aluminium) not separable (packaging coffee, milk box and juice box) |
| Combustible | Crates, boxes, wood (planks), leather (shoes, bags) and rubber |
| Incombustible | Glass, minerals and other inert materials not classified in other categories such as ceramics, pottery, porcelain, brick, plaster |

The predominant fraction was the sanitary textiles with 67.7% to 76.1% of the total dry mass. Sanitary textiles were followed by the fine fraction with 13% to 19% of the total dry mass. These values are only applicable to this region in France. This however is a great example of what could be done at a local municipality to get data on the solids in their sewers. Every sewer is different and dependent on area and sewer system properties. The categories identified in this case study helped with the categorisation of the solids in this paper.

### 3.3.2 Sanitary waste items case study

A questionnaire survey of 44 countries was undertaken by Ashley & Souter (1999) to determine what sanitary items are flushed and what items are binned. It was found that almost 75% percent of sanitary waste items found in sewers are flushed by women, and consist of tampons, applicators, sanitary towels, panty liners, cotton buds, cotton wool, condoms and toilet paper (Ashley & Souter, 1999; Ashley et al., 2004). Table 3.5 below indicates the disposal habits of the countries that completed the questionnaire. The totals do not add up to the number of countries, because in some cases items were burned.

**Table 3.5. Disposal habits for most common sanitary items (Ashley & Souter, 1999)**

| Number of disposals via | Sanitary Items | Condoms | Nappies | Toilet paper | Cotton buds | Disposable razors |
|---|---|---|---|---|---|---|
| Flushing | 13 | 13 | 2 | 25 | 9 | 1 |
| Binning | 26 | 22 | 28 | 9 | 26 | 28 |

### 3.3.3 Categories of solids

The lack of data about solids in foul (separate) sewers makes it a difficult task to label and categorise these solids. Characteristics of screenings differ between areas and systems. Solids in sewers cannot be generalised due to the variety of contributing factors such as flow regimes and operational characteristics (Ashley et al., 2005). Low income areas will have more inorganic suspended solids than high income areas. The type of system, the number of pumps, bends and turbulence can change the composition of screenings enormously. Table 3.6 presents a good example of the composition of screening at three different WWTPs.

**Table 3.6. Constituents of screenings (Sidwick, 1984: 29)**

| | Wastewater Treatment Plants | | |
|---|---|---|---|
| | A | B | C |
| Catchment Area | Compact city with peripheral settlements | Compact town with peripheral settlements | Compact holiday resort with camps and caravan sites |
| Type of Flow | Gravity but 22 pumping stations in catchment area | Mainly gravity but 13 pumping stations in catchment area | Gravity and pumped with some pumping stations in catchment area |
| Screenings removal | 100m manually raked bar screen | 25mm mechanically-raked bar screen | Mechanically-raked bar screen with disintegration of screenings and return to flow downstream |
| Visual analysis of screenings from screens (by volume, %) | | | |
| Rags | 70 | 64 | 15 |
| Paper | 25 | 25 | 50 |
| Rubber | - | - | 5 |
| Plastic | 5 | 5 | 20 |
| Vegetable matter | - | 1 | 5 |
| Faecal matter | - | 5 | 5 |

Most of the solids found in sewage originate from bathrooms. These solids consists of female sanitary items including sanitary towels, panty liners, stocking, condoms, tampons and general bathroom refuse such as cotton buds and dental floss (Gouda et al., 2003). Polypropylene-based cotton buds are known for orientating themselves in such a way as to escape through even the very finest of screens as depicted in Figure 3.2 (Ashley et al., 2005). It is known that low income groups (poorly educated) often make use of newspaper and stones for anal cleansing with blockages downstream as a result (Little, 2004). More causes of blockages are fats, oils and grease (FOG) (He et al., 2011).

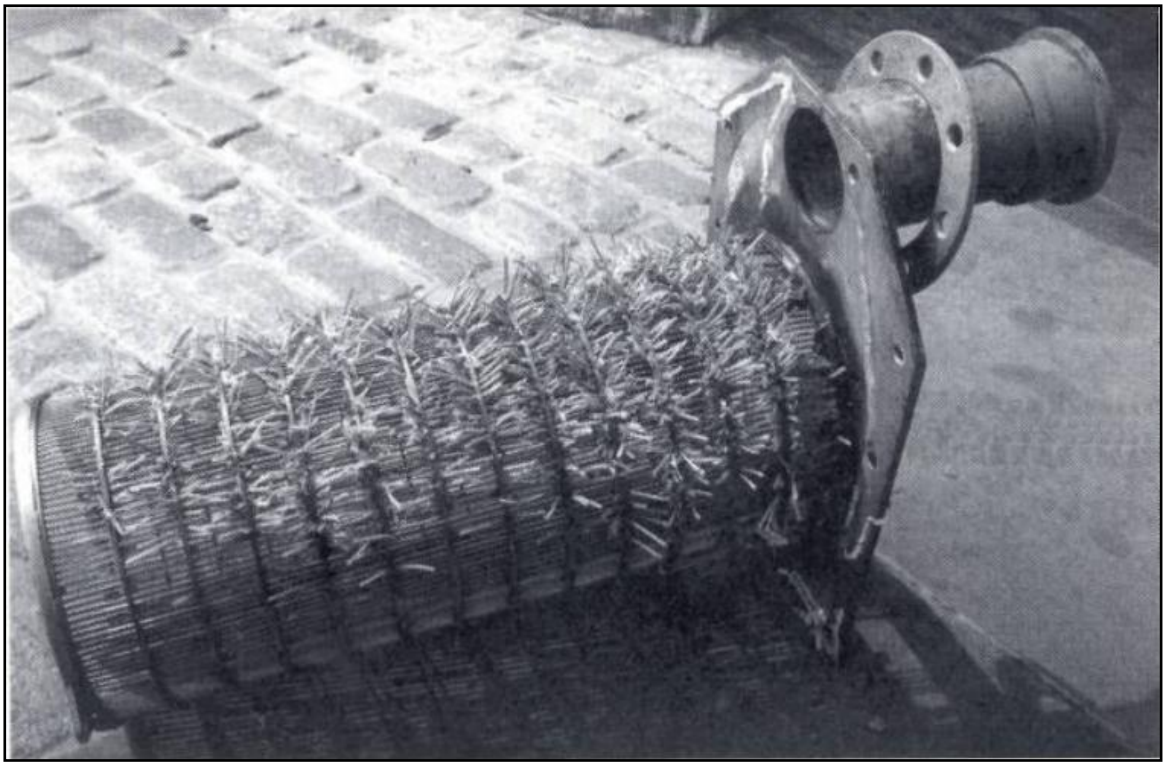


**Figure 3.2. Cotton buds clogging screen (Ashley et al., 2004)**

There is great abuse of sewer systems in the low income areas of the Western Cape (Loubser, 2011). In South Africa most of the population have a very low income and they use alternative materials for sanitary uses. These items include newspapers, magazine papers, plastic bags and sand (Steyn, 2010). There are reports of motor vehicle tyres, human bodies and even an old engine block that have clogged South African sewers (WRC, 2010).

With the help of literature, site visits and interviews a list for solids in the Western Cape sewers was compiled. The following Table 3.7 shows the index for solids in sewers.

**Table 3.7. Index of solids in sewers**

| Category | Object | Entry point |
|---|---|---|
| Cotton and wool products | Bandages | Toilet |
| | Clothing | Toilet/Manhole |
| | Cloths | Toilet/Manhole |
| | Rags | Toilet/Manhole |
| | Stockings | Toilet |
| | Under pants | Toilet |
| FOG products | Carbon black | Kitchen Sink/Restaurants/Manhole |
| | Fats | Kitchen Sink/Restaurants |
| | Food/Fruits/meat | Kitchen Sink |
| | Grease | Kitchen Sink/Restaurants |
| | Oils | Kitchen Sink/Restaurants |
| | Paint | Gutter/Gulley/Sink |
| Solids from the human body | Faeces | Toilet |
| | Fetus (human body) | Toilet/Manhole |
| | Hair | Shower/Bathroom Basin |
| | Nails | Toilet |
| Indestructible solids | Bricks | Manhole |
| | Cement | Manhole |
| | Glass | Toilet/Kitchen Sink/Manholes |
| | Rocks | Toilet/Manhole |
| | Sand | Toilet/Manhole |
| | Motor vehicle tyre | Manhole |
| Leather products | Hand bags | Toilet |
| | Shoes | Toilet/Manhole |
| | Wallets | Toilet |
| Metal products | Cans | Toilet/Manhole |
| | Cell phones | Toilet |
| | Electrical appliances | Toilet/Manhole |
| | Hair braids | Toilet/Bathroom |
| | Jewelry | Toilet |
| | Keys | Toilet |
| | Tools | Toilet |
| Other solids | Cigarettes | Toilet |
| | Feathers | Manhole |
| | Goldfish | Toilet |
| | Leaves | Toilet/Manhole |
| Paper and wrapping products | Magazine Paper | Toilet |
| | Milk boxes | Toilet/Manhole |
| | Money | Toilet |

| | | |
|---|---|---|
| | Newspapers | Toilet |
| | paper wrapping (chips) | Toilet/Manhole |
| Plastic | Condoms | Toilet |
| | Plastic bags | Toilet/Manhole |
| | Plastic bottles, bottle caps | Toilet/Manhole |
| | Plastic toys | Toilet |
| | Toothpaste caps | Toilet |
| Sanitary Textiles | Baby nappies (diapers) | Toilet |
| | Cotton buds | Toilet |
| | Cotton wools | Toilet |
| | Dental floss | Toilet |
| | Tampons and sanitary pads | Toilet |
| | Toilet paper | Toilet |
| Wood products | Matches | Toilet |
| | Twigs | Toilet/Manhole |

### *3.4 Screenings Removal Systems (SRSs)*

The CSIR (2003) gives only a brief guideline regarding screening at pump stations.

> *"Adequate protection, where necessary, in the form of screens or metal baskets, should be provided at the inlets to pump stations for the protection of the pumping equipment."*

Gross solids or screenings are sewage-derived materials larger than 6mm (Gouda et al., 2003). Screenings are typically removed by bar screens or bar racks. They are relatively large items of debris consisting of rags, plastic, cans, rocks and similar items (Water Environment Federation, 2008).

Technology used to remove solids can be measured in cost, degree of labour and effectiveness. With inexpensive technology comes a high degree on manual labour. With expensive technology comes a high degree of effectiveness and a reduction in the dependence of manual labour. This Section only addressed the SRSs available and how the operate. Each of the SRSs does remove solids, but they are used for different installations depending on the price, type of solids, type of area and space available. A SRS is also locally known as a solids handling device (SHD). Using a

SRS at sewage pump stations increase the lifetime of the pumps used, even if the advanced solids handling pumps are implemented (Worthington-Smith, 2011).

### 3.4.1 Screens

Screens are generally divided into two main types, coarse screens and fine screens (Metcalf & Eddy, 2003). Cleaning can be done either mechanically, for large scale screens or manually for small screens on a daily or weekly basis depending on the flow rates. Screens at treatment plants catch about 15 to 35% of the total mass of solids entering the treatment plant (Ashley et al., 2004). Screens can be divided as illustrated in the diagram in Figure 3.3 and their classifications are addressed in Table 3.8.

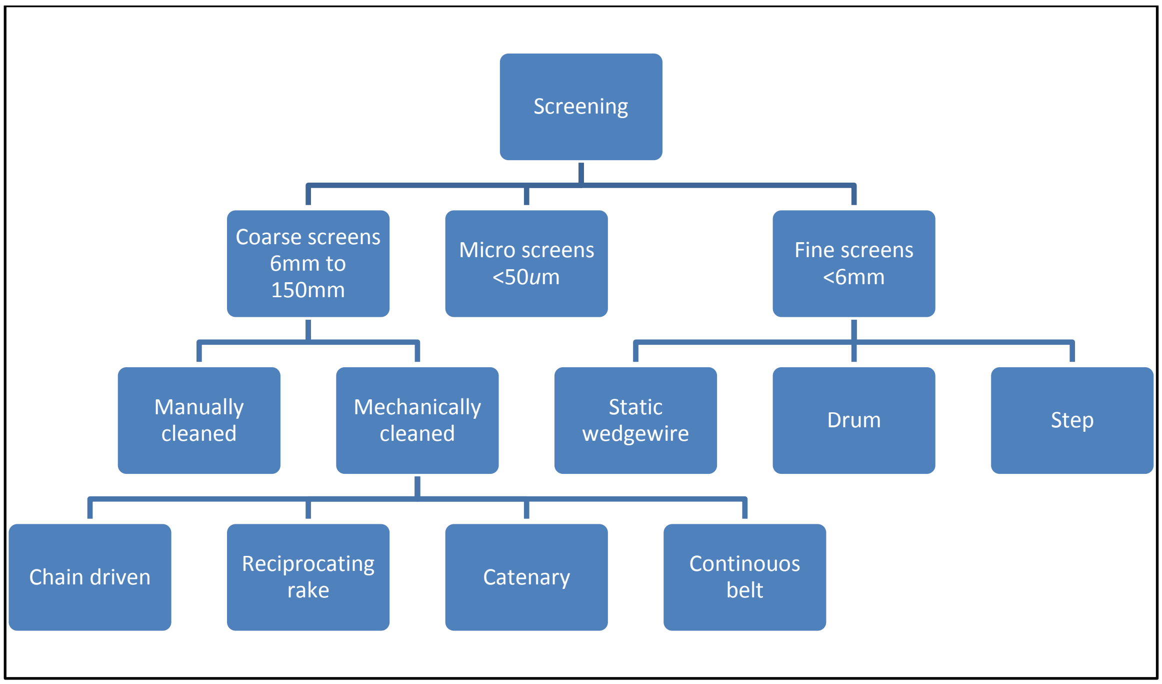



*Diagram adapted from (Metcalf & Eddy, 2003)

**Figure 3.3. Types of screens used**

Coarse screens have openings of 6mm or larger. They include manually and mechanically cleaned bar screens that remove large solids such as rags and debris. Nozaic & Freese (2009) classified screens as depicted in Table 3.8.

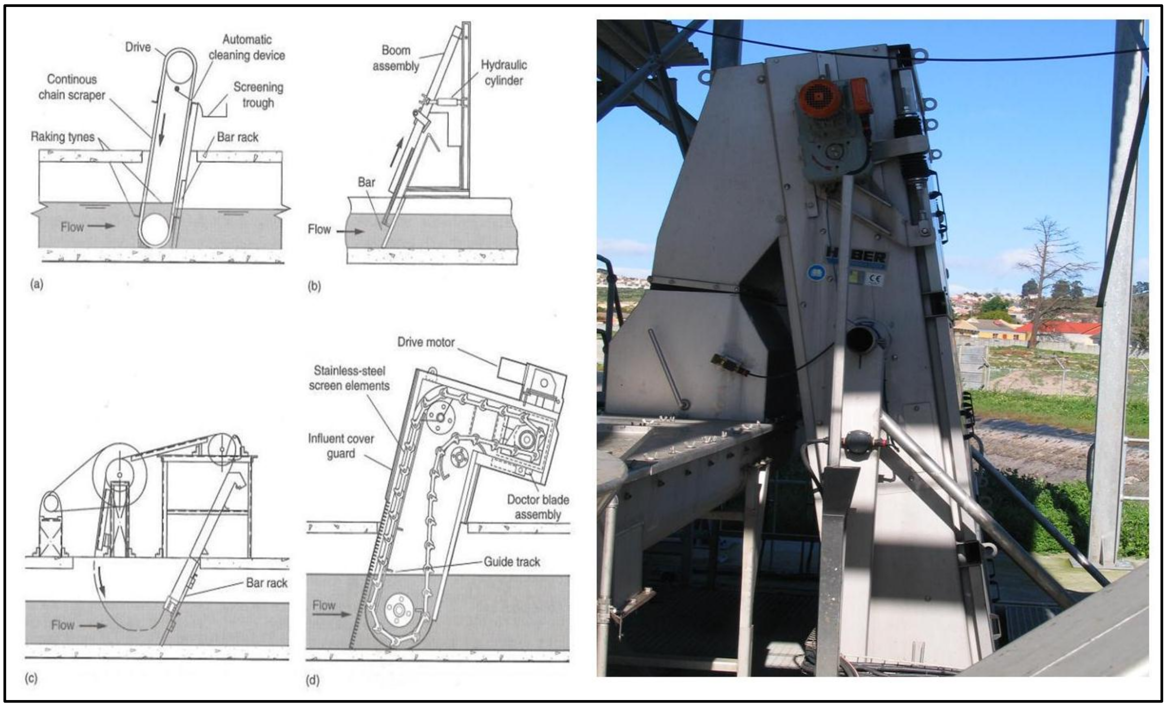
**Table 3.8. Screening device classification (Nozaic & Freese, 2009)**

| Screening Device Classification | Size Classification | Size Range of Screen Opening |
|---|---|---|
| **Bar screen** | | |
| Manually cleaned | Coarse | 25 –50 mm |
| Mechanically cleaned | Coarse | 15 – 75 mm |
| **Fine bar or perforated coarse screen (mechanically cleaned)** | | |
| Fine bar | Fine to coarse | 3 – 12.5 mm |
| Perforated plate | Fine to coarse | 3 –9.5 mm |
| Rotary drum | Fine to coarse | 3 –12.5 mm |
| **Fine Screen (mechanically cleaned)** | | |
| Fixed parabolic | Fine | 0.25 – 3.2 mm |
| Rotary drum | Fine | 0.25 – 3.2 mm |
| Rotary disc | Very fine | 0.15 – 0.38 mm |

Figure 3.4 shows coarse bar screens on the left and an improvised screen on the right. Some pump station or WWTP operators make their own improvised screens to work as is best for their needs. No screens are perfectly retentive (Ashley et al., 2005). The screens shown here are manually cleaned. For more on screens and manual cleaning refer to Appendix B.

**Figure 3.4. Types of screens in practice**

Mechanically cleaned screens are mostly used at installations with high incoming flows, such as major pump stations and WWTPs. Figure 3.5 shows the different types of mechanically cleaned coarse screens on the left and a mechanically cleaned screen in practice on the right.




*(a) front-cleaned, front-return chain driven; (b) reciprocating rake; (c) catenary; (d) continuous belt (Metcalf & Eddy, 2003)

**Figure 3.5. Mechanically cleaned screens**

Fine and micro screens are typically used at WWTPs as primary clarification or instead of primary sedimentation tanks (Nozaic & Freese, 2009). For the purpose of this study they are not addressed in further detail.

### 3.4.2 Baskets

Published work on baskets used to remove screenings is very limited. During site visits (addressed in section 4.1) it was found that baskets are simple installations which require regular maintenance. Baskets can be square, rectangular or circular depending on the shape of the sump or screening manhole. Of all the SRSs used in the field, baskets are the one technology with the least literature available. The lack of knowledge on this technology has led to the experimental testing of this screening device. This experimental testing is presented in Chapter 5. Different installations of this device are depicted in Figure 3.6.

**Figure 3.6. Screening baskets**

### 3.4.3 Macerators

Macerators, also referred to as grinders or comminutors are mechanical devices used to grind the solids to a smaller size. This is a relative expensive device, but it requires little maintenance (Hanson, 2011). Operators using macerators need training and experience, it is a dangerous tool and should be operated with caution. Macerators are not used very often, because in the case where it breaks, the maintenance takes time and is very costly. Macerators would only be installed in areas where it is essential to reduce the size of the solids. Macerators are installed in a channel and their teeth grind the larger solids to a size small enough to be handled by the pump.

Figure 3.7 shows a picture of a macerator used at the Cape Town International Airport (CTIA). This type of SRS is not very common in South Africa.


**Figure 3.7. Macerator at CTIA**

Vesilind (2003) tabulated a variety of screens and macerators, which are presented in Table 3.9.

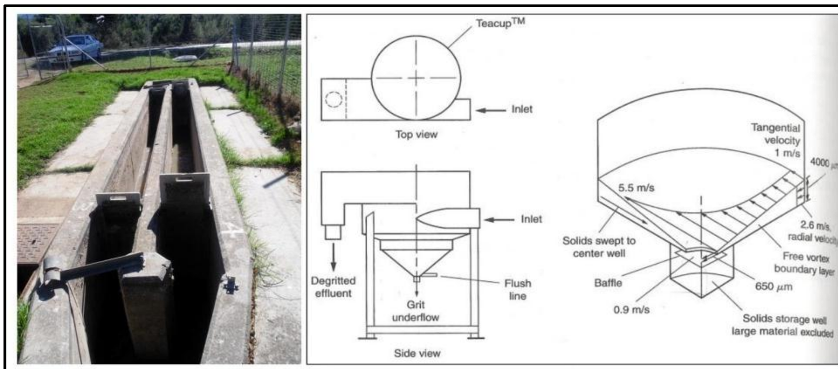
**Table 3.9. Variety of screens and macerators (Vesilind, 2003: 42)**

| Item | Range | Comment |
|---|---|---|
| **Trash rack** | | |
| Openings | 38-150mm | Commonly used on combined systems - opening size depends on equipment being protected |
| **Manual screen** | | |
| Openings | 25-50mm | Used in small plants or in bypass channels |
| Approach velocity | 0.3-0.6m/s | |
| **Mechanically cleaned bar screen** | | |
| Openings | 6-38mm | 18mm opening considered satisfactory for protection of downstream equipment |
| Approach velocity (maximum) | 0.6-1.2m/s | |
| Minimum velocity | 0.3-0.6m/s | Necessary to prevent grit accumulation |
| **Continuous screen** | | |
| Openings | 6-38mm | This type of screen effective in the 6- to 18mm range |
| Approach velocity (maximum) | 0.6-1.2m/s | |
| Minimum velocity | 0.3-0.6m/s | |
| Allowable head loss | 0.15-0.6m | |
| **Comminutor (size reduction only)** | | |
| Openings | 6-13mm | Opening a function of the hydraulic capacity of unit |
| **Grinder (size reduction only)** | | |
| Openings | 6-13mm | |
| Typical head loss | 300-450mm | In open channel |

### *3.5 Grit removal systems (GRSs)*

Ashley et al. (2004) reported at the time that knowledge regarding sediments in sewers was limited. Although some later reports on the topic could be traced during this literature review it is evident that the knowledge remains relatively limited as far as sediment in sewers is concerned. It may seem obvious that grit could practically be removed at sewer pump stations, where entry to the system, and exit of solids from the system after removal, is possible. The grit removed from sewers was studied by Nozaic and Freese (2009), who reported grit to comprise of sand, eggshells, bone chips, seeds, coffee grounds, and large organic particles, such as food waste. Larger and/or heavier particles will be found in sewers. In concept they occur infrequently enough that occasional peak flows will prevent serious blockage in the sewers (Merritt, 2009). Nonetheless, in the Western Cape this problem occurs more often. Low-income areas tend to have more problems with sand, as houses are built on sand and streets are often not paved. Sand in the Western Cape sewers is a major problem, especially in the Cape Flats. The Cape Flats is virtually flat and large amounts of sand enter the sewers (Loubser, 2011).

Sand traps and degritters are systems that remove grit. Both these systems take advantage of gravitational and centrifugal force to allow for sedimentation. Sand traps and degritters use induced flow velocities to improve sedimentation (Metcalf & Eddy, 2003). The sand trap is usually a long channel that conveys the sewage. All the heavier particles then sink to the bottom through the process of sedimentation. Degritters use a circular shape to induce a swirling motion. Centrifugal forces then allow the heavier particles to settle and they can be removed from the system. Figure 3.8 illustrates a sand trap and degritter. If grit enters the sump it can accumulate at the bottom and if the grit is then pumped it shortens the lifetime of the pump.




Sand trap Degritter

**Figure 3.8. Sand trap and degritter**

### *3.6 Effects of solids*

The presence of solids in sewers always causes problems. Ashley et al. (2004) listed the effects as presented in Table 3.10. The effects and problems caused by solids are addressed in detail in Chapter 4.

**Table 3.10. Effects of solids in sewers (Ashley et al., 2004: 165)**

| Effect caused by Solids | Description of solids cause |
|---|---|
| Reduction in hydraulic capacity, increase in surcharging, flooding | Deposition of solids in inverts, permanent or semi-permanent |
| Blockage | Deposition in inverts, build-up on walls (progressive or sudden) |
| Gases, odours, explosions | Generated from biological degradation in bed deposits (hydrogen sulphide, methane and other odorous substances) |
| Sewer corrosion | Generated from biological degradation in bed deposits in moist atmosphere |
| Pump impeller abrasion | Inorganic solids in flow (typically washed through system in wet weather) |
| Screen blockages and damage | Large solids (organic and inorganic) |
| Shock loads to treatment plants | Foul flushes and bed erosion, releasing both solids and associated pollutants |
| Rodents (Rats) | Source of food (organic solids) |
| Health risk to sewer workers | Increased hazards, infections: gases (asphyxiation, toxicity), rodents (disease transmission)<br>Access and maintenance problems increased by solids' presence |
| Fat and grease deposits - can reduce capacity or get washed out in lumps | Build up in sewer walls, particularly around ambient surface levels; can also develop into balls. |

### *3.7 Small bore systems*

Small-bore sewers are also commonly known as solids-free sewers (SFS) (Little, 2004). A solids-free sewers system is a system that disposes of the sewage, with the help of an on-site tank to settle solids out. The liquid is then conveyed into a sewer system (du Pisani, 1998). The solids remain in the tank where they are exposed to anaerobic bacteria and converted to carbon dioxide, ammonia, water and a residue, termed sludge (du Pisani, 1998). The volume of sludge builds up in the tank and must be removed at intervals, usually by vacuum tanker, and transported to the WWTP.

With most small bore systems the inceptor tank (settling tank) is located on the user's property or very near the location of disposal. Therefore users need to have knowledge of what items cannot be flushed. They also know that if they do flush an object or product that could cause a problem, they might end up with the problem on their property (Nel, 2011). This system puts the responsibility for reliability of the system in the user's hands and the advantages of SFS are presented in Table 3.11.

**Table 3.11. Advantages and disadvantages of SFS**

| Advantages | Disadvantages |
|---|---|
| Can be used with very little water | Interceptor tank at each disposal point |
| Great reduction in the amount of solids in sewers | Tanks have to be pumped, cleaned and monitored from time to time |
| Sewer pipes can be laid at flatter gradients because they do not carry solids | System does not tolerate solids |
| Ideal for flat areas, where sewer pipes cannot be laid at steep gradients | Not often used in South Africa, only small towns |
| Construction of sewer lines is easier, not at great depth | Odours may occur if not constructed properly |
| WWTP can be smaller | |
| All unwanted solids are intercepted by the tank | |
| Pumps not required to handle solids | |
| Smaller diameter pipes can be used | |

# 4. Problems at Pump Stations

There will always be a need for sewage pump stations, since sewage cannot flow under gravity at all times. Pump stations have the duty of pumping sewage to maintain flow in sewer networks. Pumping sewage holds various problems, of which one of the most common is overflows.

Parts of this Chapter were submitted to the WRC in a report (K5-2007-3 Deliverable 3) on sewer pumps and pressurized flow (Jacobs et al., 2011).

Various common problems have been documented. A list of problems has been compiled from literature, site visits and interviews. These common problems include (van der Merwe-Botha & Manus, 2011; Sidwick, 1984):

- Baskets and screens are not cleaned
- Blockages of pumps and pipelines
- Criminal activities (theft, vandalism, sabotage)
- Design deficiencies
- Electrical failure within the pump station
- Excess ingress of stormwater
- Failure of alarms and monitoring equipment
- Fouling of level probes
- Human access or absence of exclusion areas
- Human error
- Inadequate budgeting
- Inadequate inspection
- Inadequate overflow facilities
- Inadequate redundancy or standby on pumps
- Jamming of valves
- Lack of maintenance planning
- Lack of preventive maintenance

- Lack of routine inspections and condition analysis
- Level switches and controls are out of order
- Mechanical failure of duty and standby pump sets
- Odour problems
- Power outages
- Pumps that are unsuitable for sewage – certain types of pumps give chronic problems
- Settlement of grit in pipes and sumps
- Uncontrolled discharge from tankers along the reticulation system.

In this study problems at sewage pump stations were identified by means of an in depth literature study in conjunction with a combination of field visits and interviews in the Western Cape. The causes of sewage pump station problems were investigated in detail. This chapter addresses these problems and categorizes them into identifiable groups.

### *4.1 Site Visits*

Ashley et al. (2005) confirmed that there is a lack of data on solids in sewers in many countries and emphasized that more information is needed on the sewer solids of developing countries. Hydraulics and theory have their place, but a lot of experience has been gained over the years based on practical experience and considerations (WRC, 2010). Local conditions and problems unique to certain areas have to be solved “on-site”, sometimes with improvised techniques not available in text books.

Site visits were conducted to get a better overview of the state and magnitude of the problems at sewage pump stations. Various municipalities were visited and pump station inspections were conducted. All the pump stations visited were located in the Western Cape, of which the majority were unmanned stations.

The places chosen for site visits depended on the type of system used in the area. The goal was to gain knowledge of as many of the different technologies available as possible and the possible problems that occur. Different technologies included:

- Pump stations (small and large stations)

- Different solids removal techniques (screens, baskets, macerators and grit removal)
- Gravity only systems (no pump stations required)
- Small-bore systems
- WWTPs
- Different types of pump installations (submersible, immersible, screw and self priming)
- Different catchment areas classified according to income level (low-income, moderate income and high income).

It is evident that the problem with pump stations lies beyond only the design of the stations. Problems with maintenance and managing staff were visible at most of the municipalities. Nonetheless, some municipalities found that with a well designed system and regular maintenance, the problems could be reduced dramatically. At some municipalities, personnel time management perceived to be problematic. At other municipalities personnel are monitored and the pump stations work effectively. With the right attitude success can be achieved, but this is not always possible, therefore operation and maintenance should be simplified through design.

At the start of the study a field questionnaire or pump station checklist was compiled to capture relevant data at the pump stations. The field questionnaire that was developed is attached in Appendix C and can be used in the future, but it is not recommended. It was thought that if data were collected from site visits a good benchmark could be established. However, it soon became apparent that this was not a very effective method since the people operating these stations often did not have the data or knowledge of the station. The operation manual and maintenance list is often not available on site and with most of the pumps being submersible pumps, the characteristics of the pump cannot be read or collected.

It was found that the best way to collect data was to take photographs and interrogate staff about operational problems. The Pump-station standard operation inspection form, which is available in the *Waterborne Sanitation Operations and Maintenance Guide* is also a form which can be used.

The problems documented during the site visits are addressed throughout this chapter. Table 4.1 lists the locations that were visited. A more detailed list is attached in Appendix D.

**Table 4.1. Lists of pump station visits**

| **Location** | **Name of pump station** | **Notes** |
|---|---|---|
| Grabouw | Name unknown | Low income housing developments are problematic<br>Foreign objects in system |
| Genadendal | Name unknown | Low level of maintenance<br>Inefficient cleaning of baskets<br>General area around pump station are dirty<br>Plenty of sand in sewer system |
| Genadendal | Genadendal WWTP | Lacking maintenance<br>Operators lack knowledge |
| Zandvliet | Zandvliet WWTP | Lift station before treatment works |
| Scottsdene | Scottsdene WWTP | No major problems<br>Mechanical screens, degritter<br>Perfect example of well operated pump station |
| Fisantekraal | New station | Before station was in operation<br>Odour control system<br>Newest technology |
| Worcester | Worcester WWTP | Receive shock loads from chicken farms |
| Worcester | Avian Park | Foreign objects in system |
| Worcester | Zweletemba | Foreign objects in system, removed pump for inspection |
| Hermanus | Peach House | Most houses have septic tanks<br>Relatively clean sewage<br>Low flows |
| Hermanus | Zwelihle Sport | Submersible pumps |
| Hermanus | WWTP Main | Most houses have septic tanks<br>Relative clean sewage |
| Sandbaai | Sandbaai PS1 | Overflow into sea |
| Onrus | Onrus Main | Many pumps to decrease workload of pumps |
| Onrus | Onrus Rome | Generator is hidden away, limited visual impact |
| Hawston | Hawston WWTP | Developed a secondary improvised screen |
| Hermanus | Hermanus PS4 | Fats from restaurants are problematic |
| Hermanus | Mosselrivier PS | Adequate ventilation |
| CTIA | CTIA Sewage Disposal | Disposal of airplane refuse and sewage, macerator |

It was found that the predominant problem in sewers is the unwanted objects in the sewers, causing in blockages and damage. It is clear that the solids in the Western Cape sewers are dominated by refuse and sand as presented in Figure 4.1.

a) basket with rags; b) plastic and paper cleaned from screen; c) sumps filled with debris; d) electric switch found in basket

**Figure 4.1. Object found in sewers**

## *4.2 Cause of Problems*

It is vital to find out why problems occur at pump stations. This section addresses the causes of problems. These causes were either documented or noted during site visits.

### 4.2.1 Foreign objects

The accumulation of solids can lead to blockages or mechanical damage to pump impellers (Ashley et al., 2004). Objects from electrical appliances, car parts, oils, bottles, rocks and chicken feathers can and have been found in sewers (Engelbrecht, 2010). Some solids may find their way into the sewers through households and others through manholes as mentioned in section 3.1.

Negligence and abuse of South African sewers result in many problems. The unwanted objects found in South African sewers were included in Table 3.7. The effect of those solids on South African sewers is presented in Table 4.2.

**Table 4.2. Effects of solids in sewers**

| Category | Object | Problems/Effects |
|---|---|---|
| Cotton and wool products | Bandages | Blockages |
| | Rags | Blockages |
| | Stockings | Blockages/Pump damage |
| | Under pants | Blockages |
| | Clothing | Blockages |
| | Cloths | Blockages |
| FOG products | Carbon black | Blockages/thickens sewage (fat) |
| | Food/Fruits/meat | Blockages |
| | Oils | Blockages/thickens sewage (fat) |
| | Paint | Blockages/thickens sewage (fat) |
| | Fats | Blockages/thickens sewage (fat) |
| | Grease | Blockages/thickens sewage (fat) |
| Solids from the human body | Faeces (human excreta) | Reason for having sewers |
| | Fetus (human body) | Blockages |
| | Hair | Blockages |
| | Nails | Unwanted |

| | | |
|---|---|---|
| Indestructible solids | Bricks | Blockages/Pump damage |
| | Rocks | Blockages/Pump damage |
| | Sand | Blockages/Pump damage/Grit accumulation |
| | Glass | Blockages/Pump damage |
| | Cement | Blockages/Hardens in pipes and sump |
| | Motor vehicle tyre | Blockages |
| Leather products | Shoes | Blockages |
| | Wallets | Blockages |
| | Hand bags | Blockages |
| Metal products | Cans | Blockages/Pump damage |
| | Electrical appliances | Blockages/Pump damage |
| | Hair braids | Blockages/Pump damage |
| | Jewelry | Blockages/Pump damage |
| | Keys | Blockages/Pump damage |
| | Tools | Blockages/Pump damage |
| | Cell phones | Blockages/Pump damage |
| Other solids | Cigarettes | Blockages |
| | Feathers | Blockages |
| | Goldfish | Unwanted |
| | Leaves | Unwanted |
| Paper and wrapping products | Magazine Paper | Blockages |
| | Money | Blockages |
| | Newspapers | Blockages |
| | Silver chips paper | Blockages |
| | Milk boxes | Blockages |
| Plastic | Condoms | Blockages |
| | Plastic bags | Blockages |
| | Bottles and bottle caps | Blockages/Pump damage |
| | Plastic toys | Blockages/Pump damage |
| | Toothpaste caps | Blockages |
| Sanitary Textiles | Baby nappies (diapers) | Blockages |
| | Cotton buds | Accumulate in sump and build up |
| | Cotton wool | Blockages |
| | Dental floss | Unwanted |
| | Tampons and sanitary pads | Blockages |
| | Toilet paper | No real problem/dissolves fast |
| Wood products | Matches | Unwanted |
| | Twigs | No real problem depending on size |

### 4.2.2 Peak flows and FOG products

Wet weather peak flows during Western Cape winter months result in overflows at pump stations. Another time that peak flows can cause overflows is during holiday periods. During these periods some areas have a vast increase in flows. The Hermanus area is a perfect example of this, as thousands of people visit the town during vacations and sewer flows increase dramatically. Sanitary sewer overflows (SSOs) can be treated the same as combined sewer overflows (CSOs), as they both consist of stormwater, sewage and ground water, although the sanitary sewage to stormwater ratio would be higher for SSO (Field & O'Connor, 1997).

A major cause of blockages in SSOs is the hardened and insoluble FOG deposits. Of all the SSOs that occur every year in the United States (US), about 48% are due to sewer line blockages, of which 47% are related to FOG deposits that constrict flow in pipes (He et al., 2011). FOG deposits also build up around level probes which then get stuck or malfunction, resulting in the pump burning out or overflowing of the sump. Figure 4.2 shows level probes covered in FOG deposits at a pump station near restaurants in Hermanus.

**Figure 4.2. FOG deposits on level probes**

### 4.2.3 Design problems

There is often a gap between the theoretical design of pump stations by engineers and the practical operation and maintenance of pump stations by local authorities (WRC, 2010). Improper construction of pump stations can also lead to structural failures, resulting in the pump station running inefficiently.

#### *4.2.3.1 Sump*

The sump geometry has to be optimised to eliminate stagnant zones. This enhances the movement of solids in the sump with the effect that pumping can be done more efficiently (Czarnota, 2008).

Table 4.3 presents the type of problems that could occur with incorrect sump design (Jones, 2006).

**Table 4.3. Problems with sump design**

| Cause | Problem/Effect |
|---|---|
| A free fall from the inlet to the sump | Releases odours |
| Piping with excessive velocities | Unreasonable head loss and can lead to vibration problems due to turbulence in fittings and valves |
| Abrupt changes in flow direction upstream from the pump inlet connection causes vortices | Flow becomes asymmetrical and thus overloads pump shafts and bearings |
| Sump or inlet piping geometry that permits differential velocities and, thus, rotation of the fluid | Swirling in the suction pipe may reduce the local $NPSH_A$ in the core to zero and thereby cause cavitations, noise, and rapid wear |
| Discontinuities such as corners without fillets and uneven distribution of currents caused by flow past pier noses, that often result in the formation of air-entraining vortices | Formation of air-entraining vortices, which are not always visible from the surface, can be damaging |
| Stagnant areas in wastewater pumping station | Allow solids to settle in sump, accumulation of sediments |

#### *4.2.3.2 Pump*

Mechanical failure of a pump can happen due to many reasons, one of which can be selecting the wrong pump for a specific installation. The selection process described in Section 2.4.2 should be followed to select the appropriate pump for a specific installation. Failing to select the appropriate pump can lead to the problems listed below:

- Pump cavitation
- Pump under performing
- Pump over-pumping (burning out)
- Impeller failure
- Seal failure.

#### *4.2.3.3 Size and layout*

The size of the pump station should not be underestimated. The station should allow for 4 hours of emergency storage (CSIR, 2003). Allowance should also be made for wet weather peak flows and future developments. If a pump station is designed too small, the result could be regular overflows and high maintenance.

The layout of the station is important for ease of maintenance, as emphasized in Section 2.6.1. If the layout of the pump station is not optimised, maintenance can become complicated and costly.

### 4.2.4 Maintenance and operation

Screens and baskets need to be cleaned on a regular basis, otherwise they might cause blockages, resulting in sewage spills in sensitive areas causing damage and odours. Mechanically raked screens also need to be checked regularly, because their teeth are vulnerable to breakage and bending (Nozaic & Freese, 2009). The maintenance of sewage pump stations causes many problems daily throughout the Western Cape.

Maintenance, or the lack thereof, causes various problems as listed in Table 4.4.

**Table 4.4. Maintenance problems**

| Cause | Problem and effect |
|---|---|
| Not servicing pumps on regular basis | Pump failure or malfunction |
| Not cleaning sump on regular basis | Sumps can build up fat and unwanted objects |
| Not cleaning screens or baskets on daily/weekly basis | May result in overflows and blockages. |
| Not keeping records of maintenance or logging services | No data or records of previous failures, difficult to improve system without data |
| Staff not trained | Injuries or system problems as result of incompetence |

The personnel maintaining pump stations have potential hazards to overcome. This occupation unfortunately holds dangers for the employee. Van der Merwe-Botha & Manus (2011) identified the following potential hazards:

- Machines or operations present the hazard of flying objects, glare, liquids, injurious radiation, or a combination of these hazards
- Potential for injury to the head from falling objects
- Potential for foot injuries due to falling or rolling objects, or objects piercing the sole, and electrocution, where such employee's feet are exposed to electrical hazards
- Contamination or infection by waterborne diseases
- A worker falling into wastewater system
- Injuries from heavy lifting.

### 4.2.5 Eskom Power outages

Power outages result in pumps and telemetry systems not being able to operate and distribute wastewater (Winter, 2011). When pumps cannot operate due to power failure the generators should power the pumps, if available. However, if a generator is not available the situation will lead to an overflow of the station if power is not restored before the emergency storage of the sump is taken up.

### 4.2.6 Grit accumulation

Grit can have the effect of shortening the life of pumps. The ineffective removal of grit can cause it to accumulate downstream in pipes or sumps, with inefficient operation as result (van der Merwe-Botha & Manus, 2011). Sand in the Western Cape sewers is a major problem. Figure 4.3 illustrates a UDD (urine diversion dry) toilet where sand is used to cover faeces after defecation. Most low income areas have basins outside the toilets and black pots which are cleaned with sand are washed out in these basins resulting in more sand in the sewers. In the Western Cape people also make illegal connections to manholes in low income areas. These connections are often just channels dug in the ground, used to convey washing and cooking water resulting in more sand entering the sewer system. Sand also enters the sewers during the winter seasons when stormwater ingress takes place. Pump stations without sand traps or degritters suffer from more problems than stations with GRSs. The lifetime of the pumps decrease with the presence of sand. Grit also accumulates in sumps and they have to be cleaned on a more regular basis.

**Figure 4.3. Sand used in UDD toilet (Muench, 2008)**

### 4.2.7 Lack of technology

The lack of technology is most common at old pump stations. The type of problems can include the following, as presented in Table 4.5.

**Table 4.5. Problems due to the lack of technology**

| Cause | Problem and effect |
|---|---|
| No telemetry systems | Malfunctions can only be observed by physical inspection |
| No alarm systems | Sumps can overflow and pumps can fail without warning |
| No place or bin for disposing of debris cleaned from baskets or screens | Health hazard to humans and animals. Also has negative environmental impact (illustrated in Figure 4.4) |
| No water supply | Maintenance teams cannot wash baskets and their gloves after cleaning |
| No back-up pumps | Overflows might occur |
| Inadequate overflow facilities | Overflows might occur |


**Figure 4.4. Debris from baskets just thrown on ground**

### 4.2.8 Other

Other causes of problems include the following:

- Chicken farms (Smelly odours)
- Construction areas
- Industrial areas (Effluent)
- No funds for improvement
- Odours
- Safety standards, health standards
- Theft and vandalism
- Uncontrolled access.

Construction areas produce great amounts of solids as some unwanted objects including building rubble may be dumped down manholes. Engelbrecht (2010) confirmed that construction areas produce unwanted solids in the sewers of Grabouw.

The safety of employees needs to be a priority, because working with sewage can lead to health related problems. It is vital that workers take safety precautions and always wear protective gear as illustrated in Figure 4.5.

**Figure 4.5. Protective gear for working with sewage**

### *4.3 Problem Categories*

SSO can be controlled with the correct designs, but there will always be unforeseen problems such as blockages and pump failures. The City of Cape Town has five main risk categories when it comes to risks associated with pump stations. The five categories are (Samson, 2011):

- Mechanical failure of duty pump sets
- Mechanical failure of duty and standby pump sets
- Electrical failure within the pump station
- Power outages
- Screen blockages.

The overflows at sewage pump stations in the City of Cape Town for the year 2010 are illustrated in the graph in Figure 4.6.

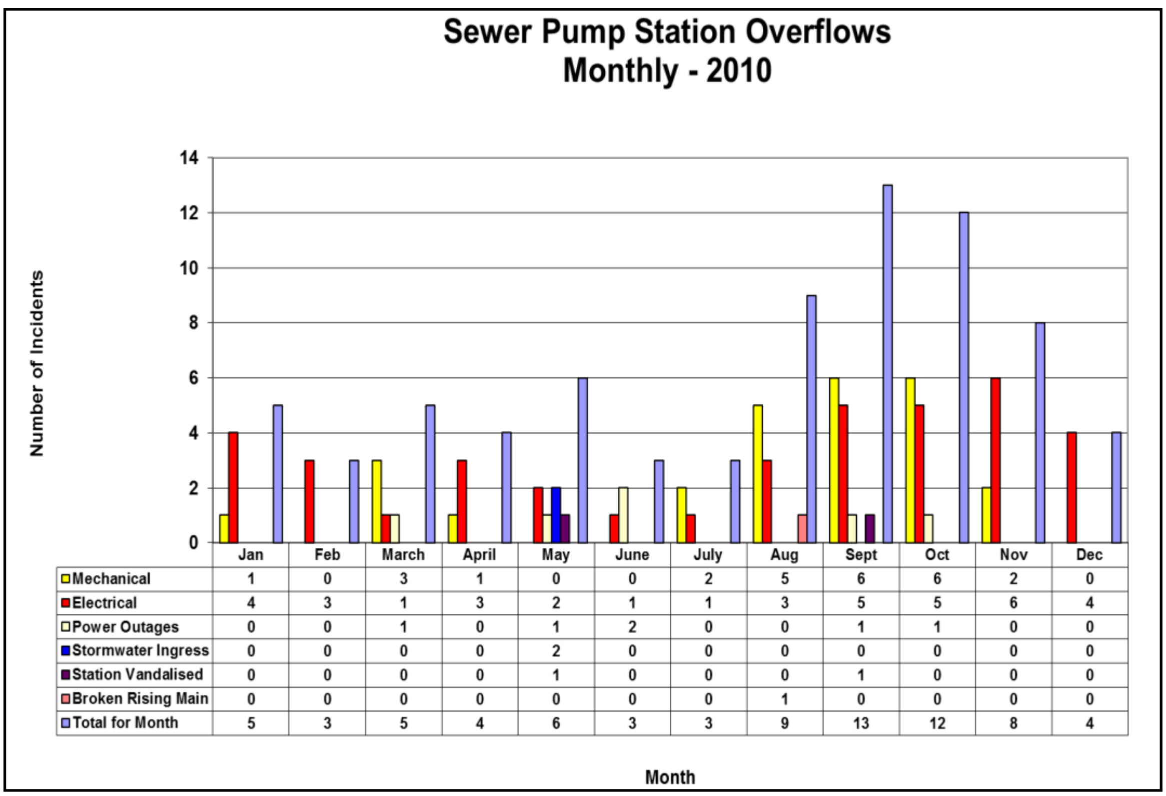



**Figure 4.6. Summary of sewage pump station problems in Cape Town (Samson, 2011)**

For the purpose of this study problems were categorized into four categories. These four categories are referred to as The 4 Os of sewage pump station problems. The 4 Os refers to overflows, odours, operational problems and other problems. All known problems will eventually lead to one of these four problems, therefore making them the four main categories.

### 4.3.1 Overflows

Overflows are the most common result of sewage pump station problems. Various problems can lead to overflows. This problem is better illustrated by the diagram in Figure 4.7.

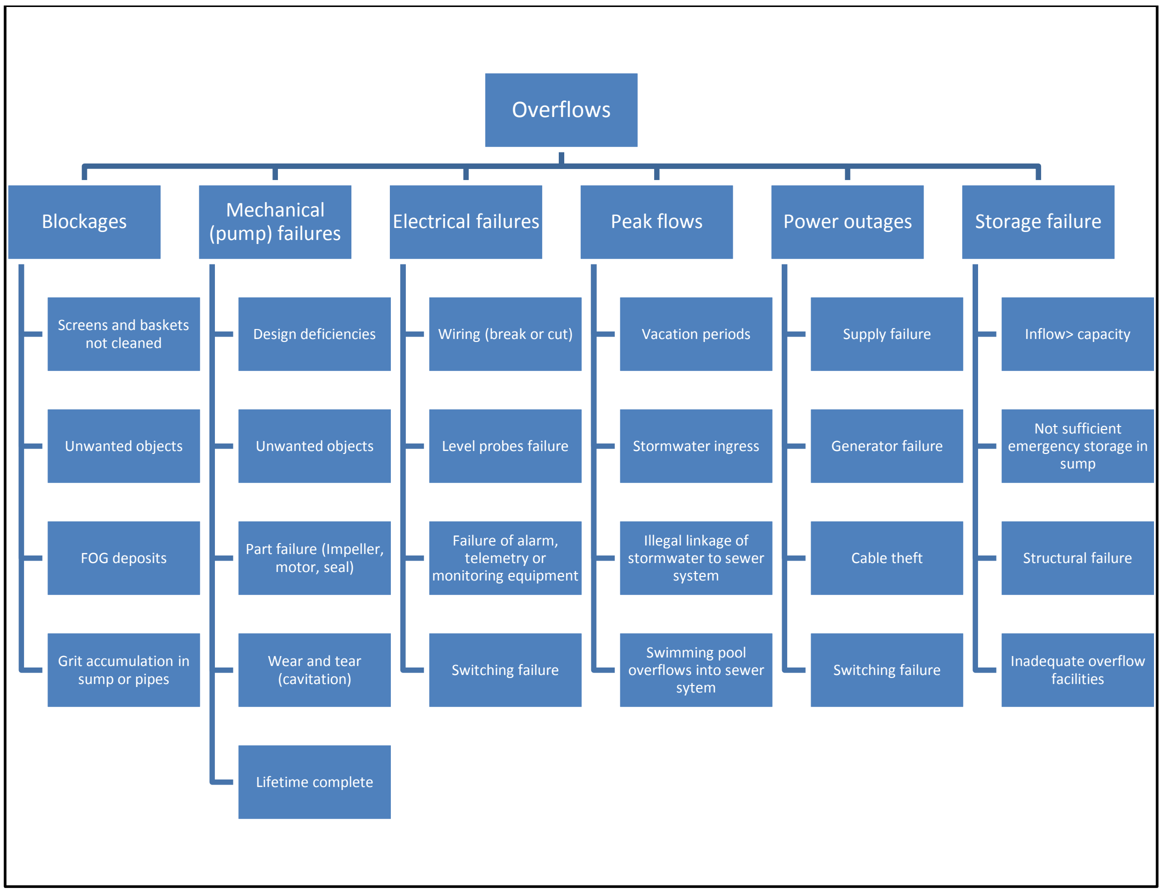



**Figure 4.7. Problems leading to overflows**

### 4.3.2 Odours

Odour problems are very common due to the smell of sewage. Odours can be present even if the pump station is working perfectly. Problems leading to odours are presented in Figure 4.8.

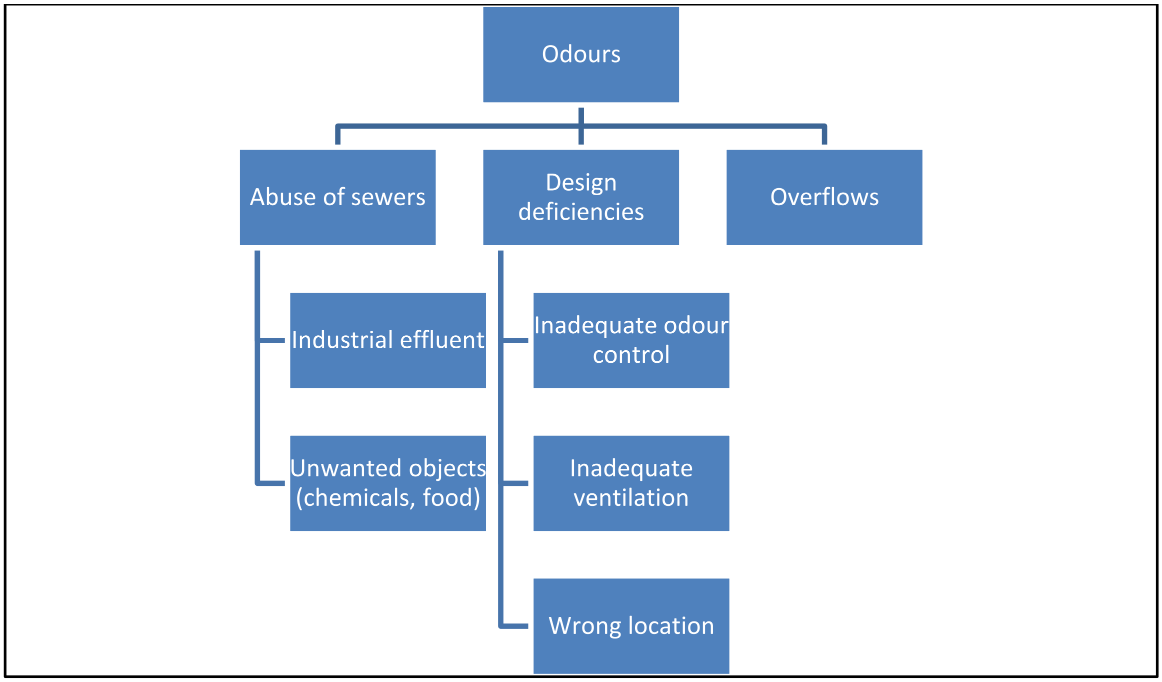



**Figure 4.8. Problems leading to odours**

### 4.3.3 Operational problems

Operational problems relate to maintenance and operation problems. The pump station may still operates, although operational problems are present, but the elimination of these problems will improve the efficiency of the pump station. Pump stations should be operated at their most efficient rate. If not, certain problems might occur and these are summarised as the following (Shiels, 2001):

- Insufficient suction pressure to avoid cavitation (level probes should be working at sufficient height)
- Excessively high flow rate for the $NPSH_A$

- Prolonged operation at lower than acceptable flow rates
- Operation of the pump at zero or near zero flow rates
- Improper operation of pumps in parallel
- Failure to maintain adequate lubrication for the bearings
- Failure to maintain satisfactory flushing of mechanical seals.

Figure 4.9 illustrates the problems leading to operational problems.

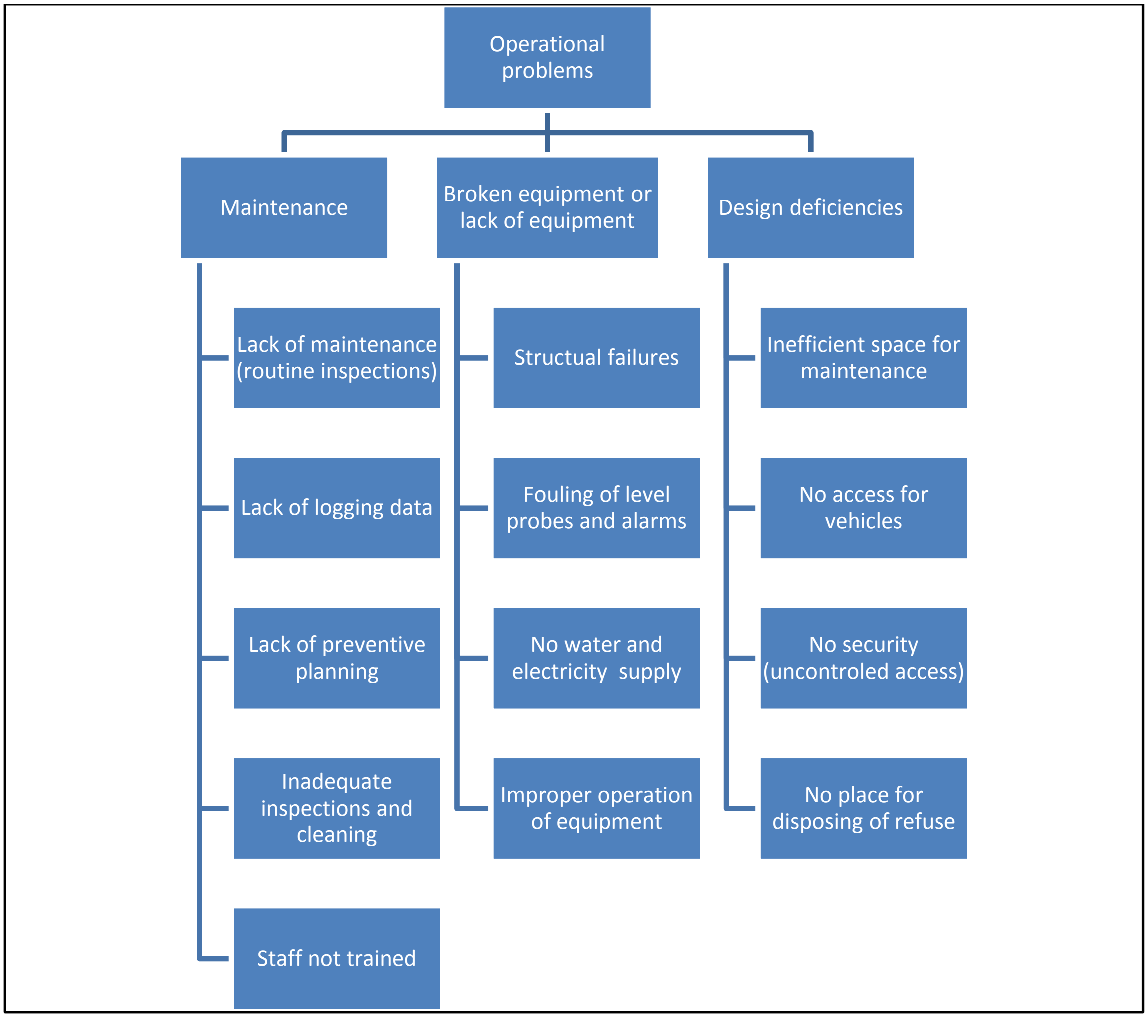



**Figure 4.9. Problems leading to operational problems**

### 4.3.4 Other problems

Other problems refer to all problems not directly affecting the operation of pump stations. These problems include criminal activities and health and safety issues. Criminal activities are present throughout South Africa, including the Western Cape. In Worcester and Grabouw theft is a large problem and fencing around the pump stations is a necessary first line of defence (Engelbrecht, 2010; Steyn, 2010). Some stations even have alarm systems to ensure that vandalism and theft is reduced. The diagram in Figure 4.10 illustrates other problems at pump stations.

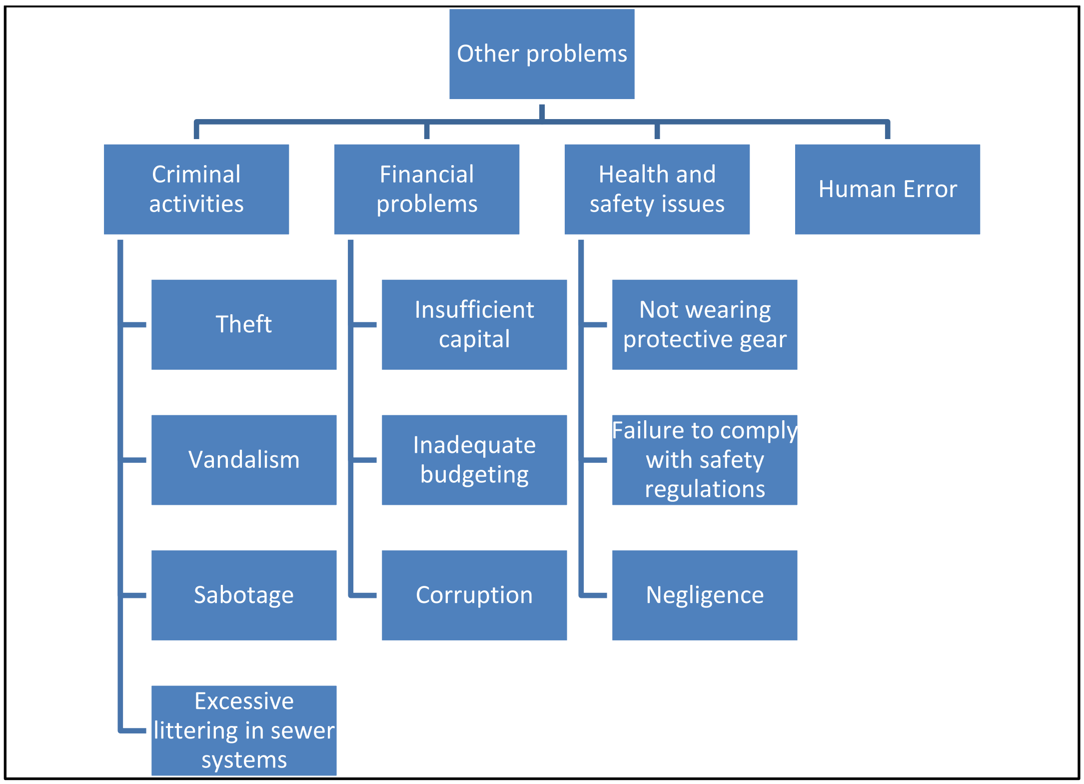



**Figure 4.10. Other problems at pump stations**

### *4.4 Solving the problem*

The lack of knowledge regarding pump stations and how they should be operated and designed is a major problem. A possible solution for this is to get proper design guidance and to convey the correct knowledge to the appropriate (operators and designers) people. A concept DST is proposed in Chapter 6 as a possible solution. A DST could help with identifying, minimising and eliminating sewage pump station problems in the future. Eliminating or minimising problems improves the functioning of a pump station. Many authors have compiled precautionary control measures, guidelines and methods to reduce or eliminate the problems at sewage pump stations. A number of these measures are presented in this section, but the main focus is on the removing or reducing of solids. Solids are the cause of the majority of the problems at pump stations.

#### 4.4.1 Solids

There are two ways to approach the problem of solids in sewers. One is to remove the solids at CCPs along the sewer system, whether at pump stations or at WWTPs. The other is to stop the problem at the source, by educating the public on what solids sewer systems can handle.

To effectively remove solids at CCPs the correct systems need to be in place. The SRS and GRS addressed in Section 3.4 and 3.5 have to be incorporated with the design of pump station to work effectively. These technologies can work effectively with the correct implementation and operation. Removing solids from sewers is not a pleasant job. Manually cleaning screens and baskets is considered to be an occupational hazard and a health threat. It is unfortunate that humans have to work with solids, but with the right systems and precautionary measures cleaning can be done with more ease. The following list contains some guidelines to more effectively remove solids at pump stations:

- Always wear protective gear
- Asset management
- Odour control
- On site solutions (often works the best)
- Operate systems to their optimum potential

- Provide maintenance manuals and checklists
- Regular cleaning of screens and baskets
- Regular maintenance of equipment
- Staff management (monitoring of personnel)
- Stock back-up equipment and spare parts
- Training of personnel (straightforward to operate most systems).

To be more proactive, unwanted solids should never enter sewer systems. Public participation and willingness to participate are required to achieve sustainable developments (Ashley et al., 1999). Public prosecutions, awareness, knowledge and ownership need dramatic improvement to achieve sustainable development. Radical changes need to be made in the structure and management of societies, policies, aid programmes, social habits and educational systems in order to prevent pollution (Niemczynowicz, 1993). South Africa is in need of educational campaigns teaching the public the effects of their habits. Scotland has had the *Think before you flush* campaign and once the public became aware, they became more responsible users. It is believed that a change of at least 50% of those flushing sanitary items could be achieved with public awareness campaigns, if implemented correctly (Ashley et al., 2005). The campaign poster is illustrated in Figure 4.11.

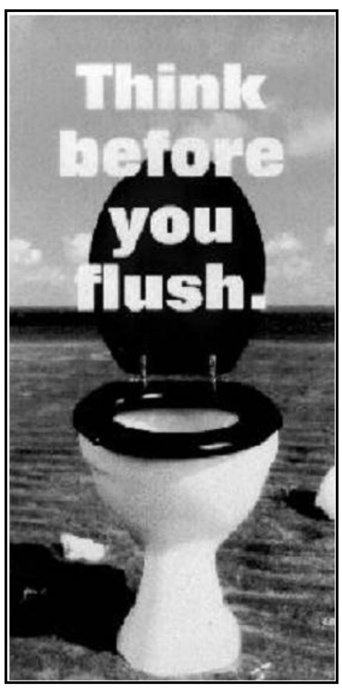



**Figure 4.11. Think before you flush poster (Ashley et al., 2004: 211)**

### 4.4.2 Operation and Maintenance

Van der Merwe-Botha & Manus (2011) listed control measures to improve the efficiency of sewage pump stations:

- Ensuring contingency plans are in place in case of unforeseen incidents
- Ensuring working alarm and failure monitoring equipment
- Implementing stormwater reduction activities, e.g. seal off manholes, replace manhole covers
- Availability of mobile or fixed power generating plants
- Overflow retention dams
- Rapid response to alarm conditions
- Removal of grit from sewers
- Replacement of old systems and pipes
- Routine checks and monitoring
- Security from access by animals and criminals
- Security to prevent unauthorised access and tampering.

### 4.4.3 Mechanical

Regular maintenance of pumps is essential. The Water Environmental Federation provides (2008) a trouble shooting guide for centrifugal pumps, presented in Table 4.6.

**Table 4.6. Troubleshooting guide (Water Environment Federation, 2008: 8-44)**

| Problems | Causes | Solutions |
|---|---|---|
| No liquid delivered | Pump not primed. Speed to low | Prime pump. Check voltage and frequency |
| | Air leak in suction or stuffing box | Repair leak |
| | Suction or discharge line plugged | Unplug line |
| | Wrong direction of rotation | Correct direction of rotation |
| | Discharge valve closed | Open discharge valve |

| | | |
|---|---|---|
| Not enough pressure | Speed too low<br>Air leak in suction of stuffing box<br>Damaged impeller or casing<br>Wrong direction of rotation | Check voltage and frequency<br>Repair leak<br>Repair or replace<br>Correct direction of rotation |
| Motor runs hot | Liquid heavier and more viscous than rating<br>Packing too tight<br>Impeller binding or rubbing<br>Defects in motor<br>Pump or motor bearing over-lubricated | Increase dilution factor<br>Adjust packing<br>Align impeller properly<br>Repair or replace motor<br>Lubricate bearing properly |
| Stuffing box overheats | Packing too tight, not enough leakage of flush liquid<br>Packing not sufficiently lubricated and cooled<br>Wrong grade of packing<br>Box not properly packed<br>Bearings overheated<br>Oil level too low or too high<br>Improper or poor grade of oil<br>Dirt or water in bearings<br>Misalignment<br>Over greased | Adjust packing<br>Adjust packing<br>Replace packing<br>Properly pack box<br>Grease properly, check tightness.<br>Adjust oil level to correct level<br>Replace with proper grade of oil<br>Clean and regrease bearings<br>Align properly<br>Grease bearings properly |
| Bearings wear rapidly | Misalignment<br>Bent shaft<br>Lack of lubrication<br>Bearings incorrectly installed<br>Moisture in oil<br>Dirt in bearings<br>Over lubrication | Align properly<br>Repair or replace. Correct source of vibration<br>Lubricate bearings<br>Reinstall bearings properly<br>Replace oil<br>Clean and relubricate<br>Lubricate properly |
| Not enough liquid delivered | Air leaks in suction of stuffing box<br>Speed too low<br>Suction or discharge line partially plugged<br>Damaged impeller or casing | Repair leaks<br>Check voltage and frequency<br>Unplug line<br>Repair or replace |

| | | |
|---|---|---|
| Pump works for a while then loses suction, vibration | Leaky suction line | Repair suction line |
| | Air leaks in suction of stuffing box | Repair leaks |
| | Misalignment of couplings and shafts | Properly align couplings and shafts |
| | Worn or loose bearings | Replace or tighten bearings |
| | Rotor out of balance | Balance rotor |
| | Shaft bent | Repair or replace shaft |
| | Impeller damaged or unbalanced | Repair or balance impeller |

### 4.4.4 Safety

The CSIR (2003) provides the following safety precautions:

- All sumps and dry wells should be adequately ventilated
- Handrails should be provided to all landings and staircases and to the sides of open sumps and dry wells
- Skid-proof surfaces should be provided for all floors and steps
- Layout of the pumps, pipework and equipment should allow easy access to individual items of equipment without obstruction.

# 5. Laboratory Experiment

The laboratory experiment investigates the current use of baskets at pump stations as a solids removal system (SRS). As far as the author could determine there is no published work on a similar experiment that has been conducted on screening baskets in South Africa.

Baskets can be operated inside the sump or in a screening manhole (communicator vault). There is literature available on screens and how they operate, but very little literature was found on baskets. Baskets are used in practice and Theart (2011) confirmed that they are built frequently for pump stations by his company, Zwangavho Trading. There is brief reference to baskets in some local publications by CSIR (2003) and van Vuuren & van Dijk (2011), but no literature could be found during the literature review on how efficiently baskets work and how they should be operated. The intention with the laboratory experiment was to gain knowledge of basket performance and to identify future research needs.

## 5.1 Methodology and aim

This section outlines the methodology used to approach the experiment. After conducting site visits it was clear that baskets are often used in practice. However, conditions under which the baskets should be operated remained unclear. One of the major uncertainties found by the author was at what level (height) the basket should be operated in relation to the surface of the fluid in the sump. The heights at which baskets were operated vary at pump stations. At some installations the basket was beneath the surface and at others above the surface level. This was one of the main focuses of the laboratory experiments. Two variable factors were chosen to ensure that tests did not get too complicated. The predetermined factors are the time of the solids in the water (retention time) and the height of the basket above the liquid in the sump. All other influencing factors remained consistent throughout the testing.

The aim of the tests was to evaluate the following:

- The efficiency of the basket at different operating heights in relation to the liquid surface level
- The efficiency of the basket in catching certain predetermined solids
- The efficiency of the basket with certain predetermined solids at different retention times.

The entire design of the experiment was based on findings during field visits and installations found in practice. The experiments had certain limitations and assumptions were made to evaluate the basket's efficiency.

The assumptions made are presented in Table 5.1.

**Table 5.1. Assumptions for laboratory experiment**

| Assumptions | Motivation |
|---|---|
| 160mm pipe was used (150mm inside diameter) | Most common (found during site visits) |
| Flow must be above 0.7m/s and less than 2.5m/s | Standards for self cleansing sewers (CSIR, 2003) |
| Slope must be more than 1:200 | Minimum sewer gradient (CSIR, 2003; van Vuuren & van Dijk, 2011) |
| Basket tested at two heights | Predetermined |
| Solids tested at two different retention times | Predetermined |
| Constant flow conditions | Easier to test, otherwise there are to many variable factors and only limited pump capacity was available * |

*The pump available for the water supply had limited capacity and therefore the flow was limited

## *5.2 Design*

The basket used in the tests is based on a square basket used in a screening manhole as illustrated in Figure 5.1. The basket in Figure 5.1 has openings of 40mm, the basket used in the laboratory experiment had 50mm openings as presented in Figure 5.2. A 50mm opening was chosen on the recommendation of Theart (2011), the manufacturer of the screening basket. According to Theart (2011) the 50mm opening screening basket is manufactured by his company Zwangavho Trading CC on a regular basis. The experiment was done on a full scale model.

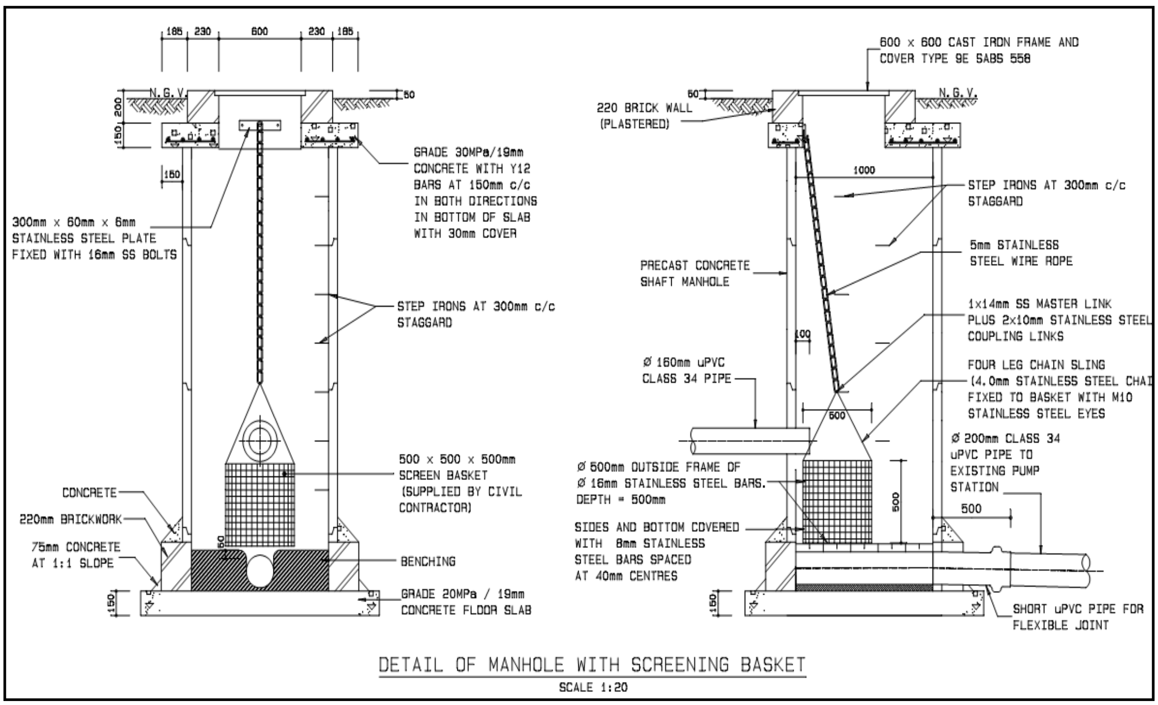



**Figure 5.1. Screening manhole with screening basket (Strassberger, 2011)**

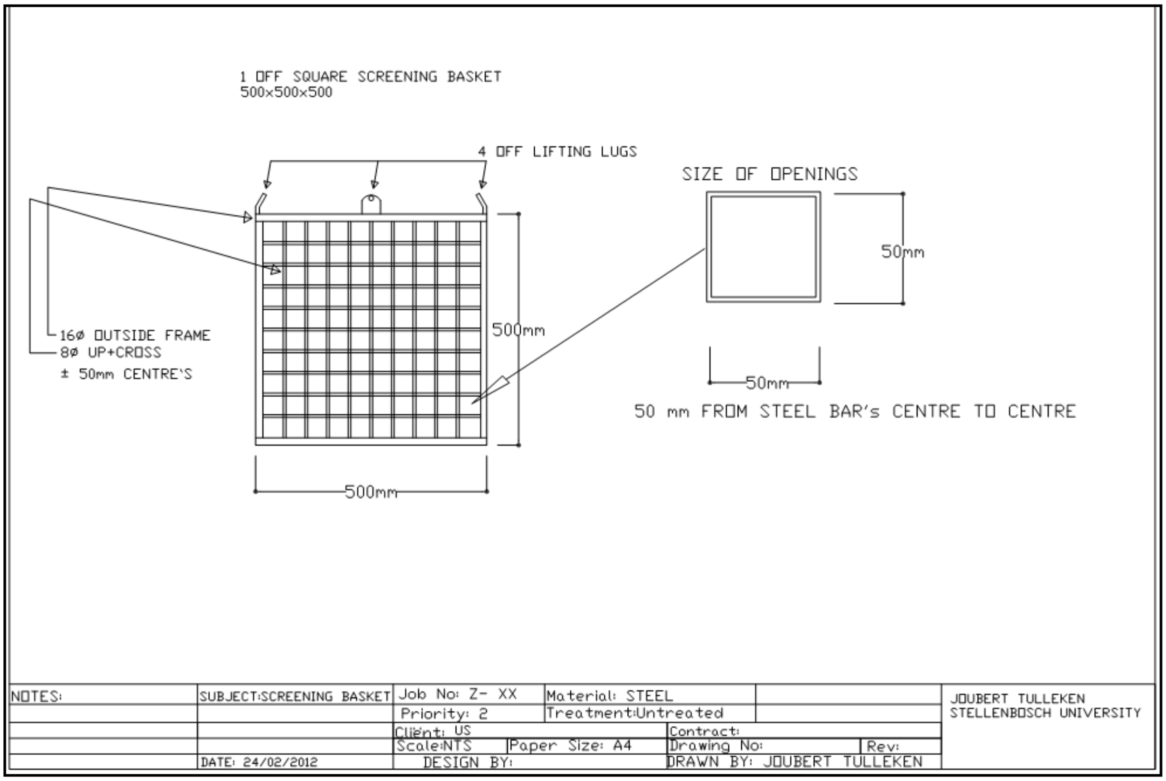



**Figure 5.2 Design of screening basket used in experiment**

The experiment was conducted in the water laboratory of Stellenbosch University. The available space was limited to 5m x 3m, within which a design was attempted to test efficiency of the screening basket. The only requirements were that the slope had to be more than 1:200 and the flow velocity between 0.7m/s and 2.5m/s. Manning's equation was used to determine the velocity in the pipe.

$$Q = \frac{1}{n}\frac{A^{\frac{5}{3}}}{P^{\frac{2}{3}}}S^{\frac{1}{2}} \quad \text{(Chadwick et al., 2004)} \qquad \text{....6}$$

Where

Q = Discharge ($m^3$/s)

A = Cross-sectional area of the flow ($m^2$)

P = Wetted perimeter (m)

S = Slope of the pipe

n = Manning's roughness coefficient

For a circular pipe sections (Haested et al., 2004):

$$A = \frac{D^2(2\theta - sin2\theta)}{8} \quad ....7$$

$$P = D\theta \quad ....8$$

$$\theta = cos^{-1}(1 - \frac{2y}{D}) \quad ....9$$

$$V = \frac{Q}{A} \quad 10$$

Where

D = Diameter of pipe (m)

θ = Angle (radians)

y = depth of flow (m)

v = velocity of flow (m/s)

A Manning roughness coefficient of 0.013 was selected for the plastic pipe (van Vuuren & van Dijk, 2011). Before construction was done, the angle of the slope was chosen to be 1:40 with the limited space. For that slope, a velocity of more than 0.7m/s and less than 2.5m/s would be present for the flow depth used with an inside pipe diameter of 150mm.

However, after construction the slope was 1:43, for which a velocity of more than 0.7m/s and less than 2.5m/s was present for the flow depth used.

The following values were applied to all the tests in the experiment:

D = 0.15m (inside diameter)

n = 0.013

S = 1:43

y = 0.035m (depth measured during tests)

These values were substituted into the equations as mentioned above and the following was calculated:

A = 0.0052m$^2$

P = 0.15m

$\theta$ = 1.008 radians

**v = 1.24m/s**

These values were consistent for all tests and they met the necessary requirements. The flow was measured during tests and the velocity remained constant at approximately 1.2m/s for all tests.

In order to simulate a full scale experiment the following components were required:

- Water supply
- Inlet pipe
- Sump
- Basket
- Hoisting equipment (pulley system)
- Solids to test.

A water tank was used as a sump. An outlet pipe of the same size as the inlet pipe was inserted into the tank to ensure that the water level remained consistent. In this way the surface level of the liquid was controlled and the test could be done with ease. The square basket was ordered from Zwangavho Trading (manufacturing company) as presented in Figure 5.2 with openings of 50mm.

The design was done in AutoCAD (2D) and Inventor (3D) as illustrated in Figure 5.3 to 5.6. Figures 5.3 to 5.5 illustrate the dimensional design drawings of the top, side and front views respectively and Figure 5.6 presents the 3D design of the experiment. The actual model is presented with the photo in Figure 5.7. More photos of the model are attached in Appendix E.

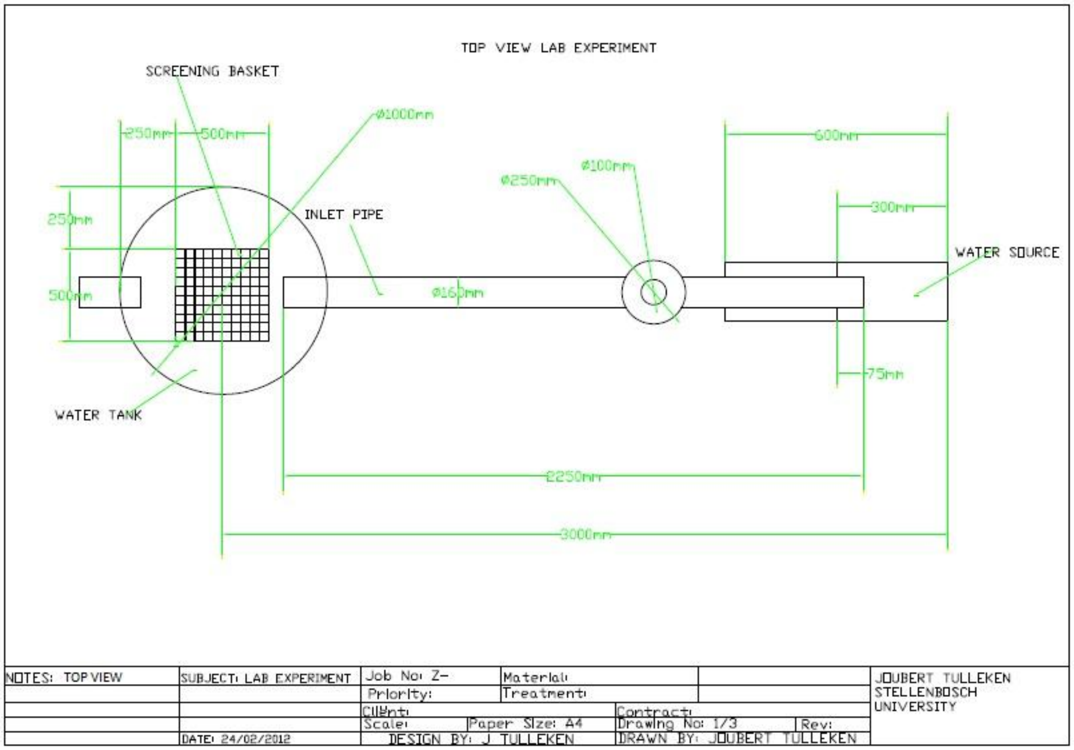



**Figure 5.3 Top view of lab experiment**

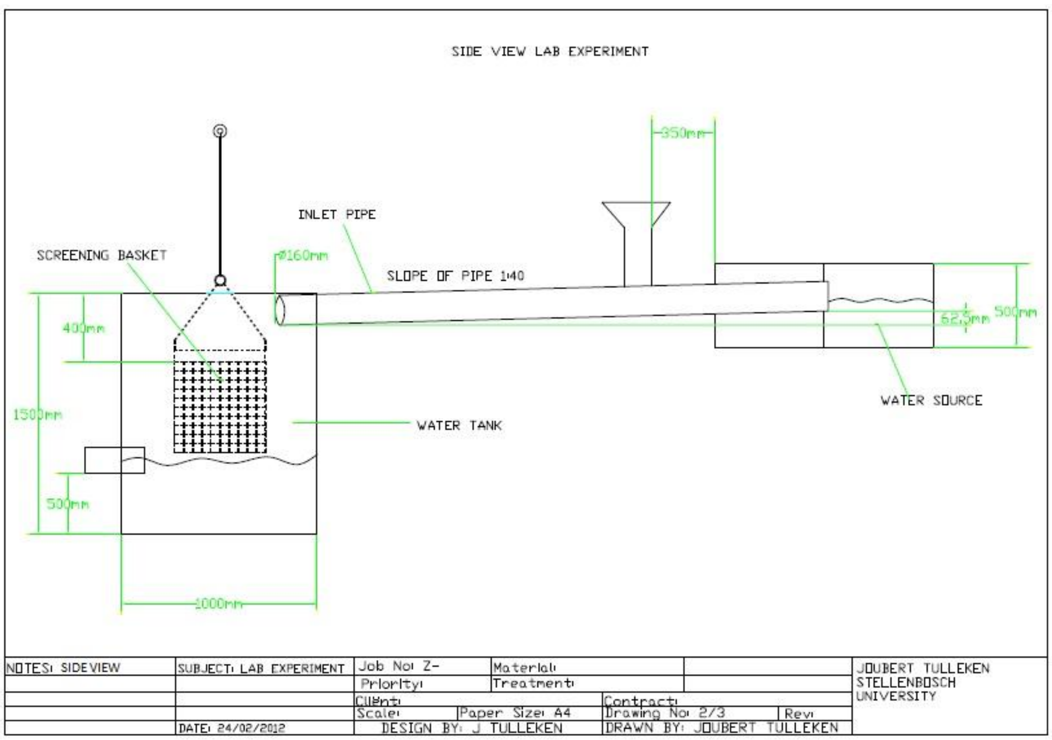



**Figure 5.4 Side view of lab experiment**

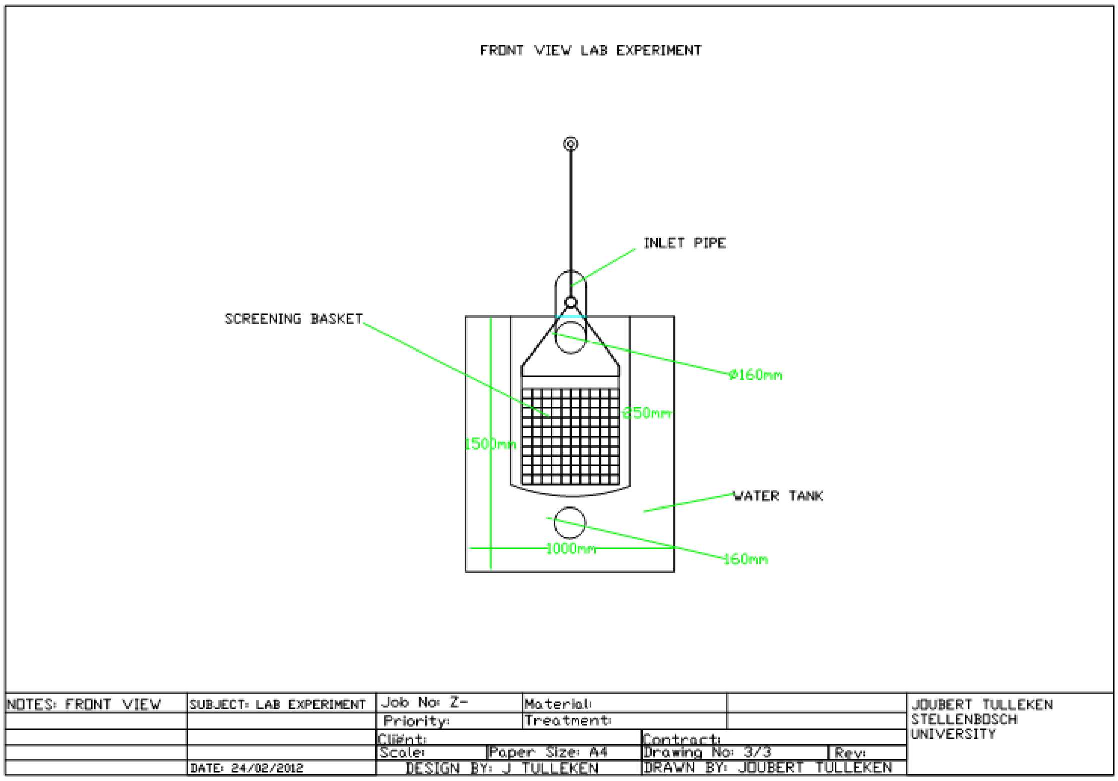



**Figure 5.5 Front view of lab experiment**

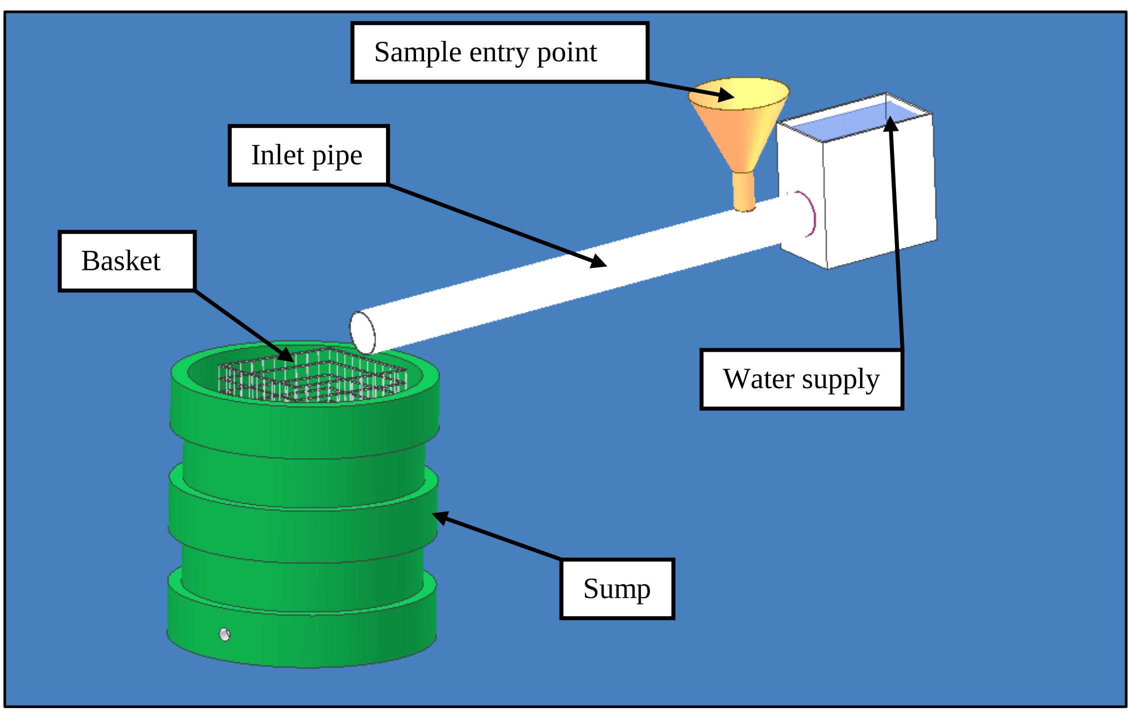



**Figure 5.6. Design of laboratory experiment**

**Figure 5.7. Actual model in laboratory**

### *5.3 Testing phase*

Testing took approximately four weeks to complete. For the purpose of the experiment sewage was supplemented with water. All the tests were done with the retention time of the solids and the height above the water as the two variables. All solids were tested at 0 hours and 1 hour retention time. The basket was tested at a height above the water and halfway submerged in the water. All the solids tested were tested five times for each scenario. The following four scenarios were tested:

- Solids at 0 hours retention time with basket above water
- Solids at 0 hours retention time with basket halfway submerged in water
- Solids at 1 hour retention time with basket above water
- Solids at 1 hour retention time with basket halfway submerged in water.

### 5.3.1 Solids tested

A total of 6 different solids were tested. They are presented in Table 5.2 below with the motivation for each solid.

**Table 5.2. Solids tested in experiment**

| Solid | Quantity tested in each test | Motivation |
|---|---|---|
| Toilet paper | 250g | Most used sanitary item |
| Newspaper | 250g | Used for anal cleansing in low income areas |
| Magazine paper (gloss) | 250g | Used for anal cleansing in low income areas |
| Cotton buds | 100 buds | Poses a great problem in sewers |
| Dental floss | 50 pieces of 0.5m each | Often used sanitary item |
| Stockings | 10 pairs | Poses a great problem for pumps |

As presented in Section 3.2, some items cause problems in sewers and have to be removed where possible. Steyn (2011) and Trautmann (2011) found that low income areas use various products for sanitary purposes other than what is used conventionally. This was the main motivation for testing newspapers and magazine papers. Ashley et al. (2005), Gouda et al. (2003) have found that cotton buds are major problem and Crombie (2011) found this to be true for South African sewers. Stockings are a threat to pumps, as they can stretch to great lengths, tangle around the shaft or get caught by the impeller and causes pump damage (Trautmann, 2010). Figure 5.8 shows the products tested in the laboratory experiment.


a) toilet paper; b) newspaper; c) magazine paper; d) cotton buds; e) dental floss; f) stockings

**Figure 5.8. Products tested in experiment**

### 5.3.2 Method

The products tested are referred to as samples. Samples were inserted at the top of the inlet pipe as shown in Figure 5.6. All the products were inserted into the model one by one. This took approximately 3-4 minutes. Samples were then left in the basket for 1 minute and were then removed. The samples caught by the basket were then counted or weighed to get representative results. A total of 100 samples were tested and some samples had to be prepared before they could be tested. Cotton buds and stockings did not need any preparation. All paper products (newspaper and magazine paper) were cut into A4 size and then folded twice before being entered into the model. The dental floss was cut into 0.5m meter lengths to simplify tests. Toilet paper was folded three to four times to form a presentable sample.

All samples tested at 0 hours were first wetted before being entered into the model, which was done by dipping the product into a bucket of water.

All the samples tested after 1 hour retention time were put in water for a period of 1 hour. The samples were stirred every 5 to 10 minutes so simulate the movement they would experience during flowing through pipes. A period of 1 hour was chosen to be consistent, in practice every area would differ depending on the type of system, size of area, slope of pipes, diameter of pipes and the type of area. The worst case scenario would be 0 hours retention time.

The worst case scenario for the pump station would be the solids that enter the network just before the station, as illustrated in Figure 5.9. The sewage leaving area 1 would reach the pump station almost immediately while sewage coming from area 4 would take longer to reach the pump station.

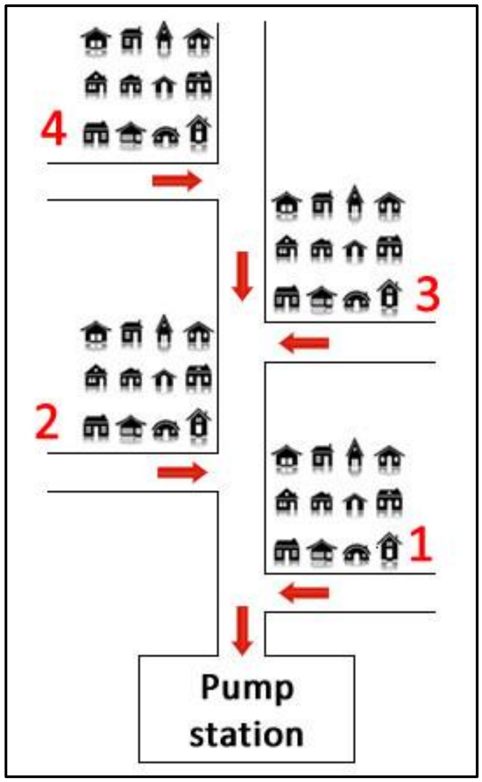



**Figure 5.9. Illustration of different retention times**

All samples were weighed or counted before they were inserted into the model and the quantity caught by the basket was also counted or weighed. All samples that had to be weighed were dried at room temperature for a period of two weeks. The case study in Section 3.3.1 oven dried samples for a week at 80°C, unfortunately such a facility was not available. This factor did not influence the results, because it was consistent for all the samples.

For tests where the basket was above the water surface the basket was placed just below the inlet pipe, as shown in Figure 5.10. The surface of the water was a distance of 650mm below the inlet pipe. For more photos of samples before and after testing refer to Appendix E.

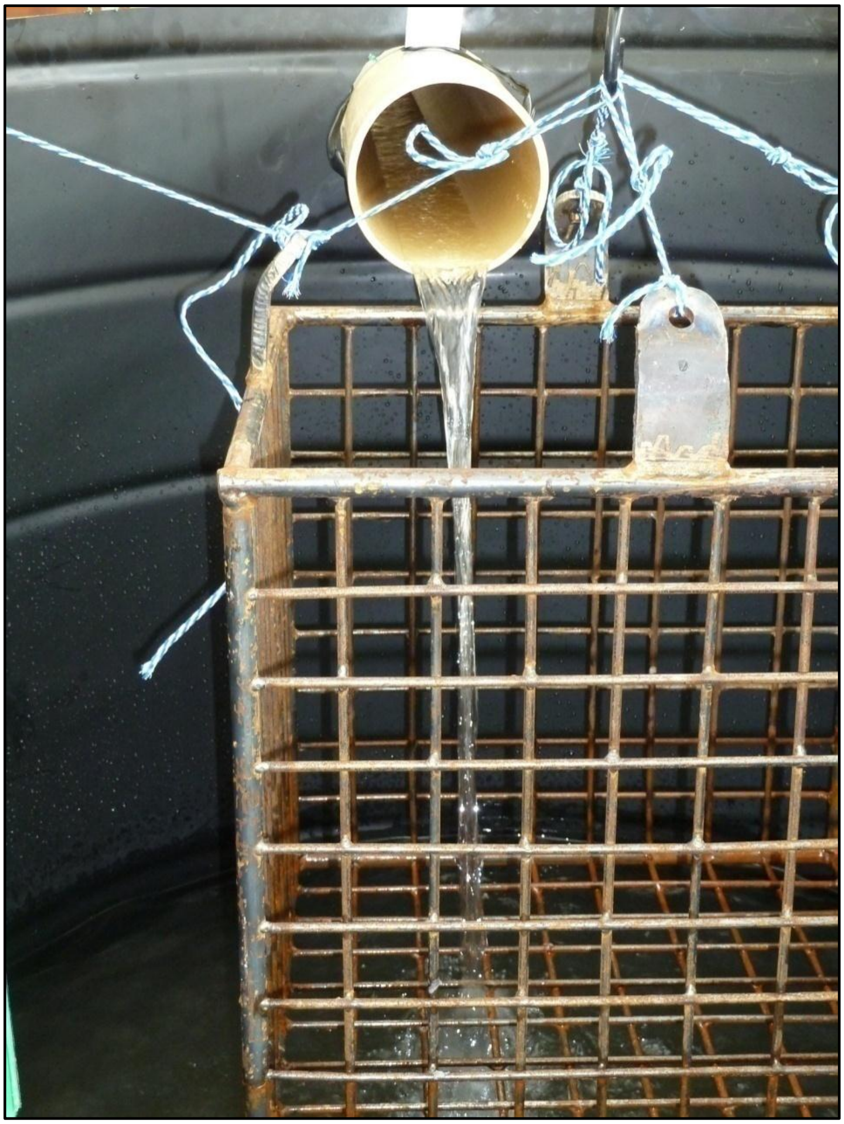


**Figure 5.10. Inlet pipe and basket**

### 5.3.3 Limitations

The results of the experiment were case specific. The experiment is sensitive to any changes that might be made and results might differ. Below is a list of factors that might give different results.

- Diameter of inlet pipe
- Different flow velocities
- Different operating conditions

- Distance water falls before entering the basket
- If basket was same size as sump (as shown in Figure 3.6)
- If FOG deposits were added.
- Orientation of the basket
- Size and quantity of samples used
- Size of basket openings
- Size of the basket
- Size of the sump
- Slope of inlet pipe
- Time basket stays in water
- Time samples stay in basket
- Type of sewer system
- Use of sewage instead of water
- Whether a pump was in the sump.

## *5.4 Results*

For baskets to work efficiently they should pass paper products, which are pumpable. The basket should only catch solids that could damage the pump and the rest of the sewage should be kept in motion and pumped away. In this way the basket would not fill-up too fast and reduce the maintenance costs and time.

### 5.4.1 Toilet paper

Toilet paper was only tested once, because it was clear that the basket did not catch it. The toilet paper disintegrated as soon as it hit the basket. This shows that toilet paper does what it is designed for. 250g of the product was put in the model at 0 hours and only 8g was caught by the basket, as illustrated in Figure 5.11. Toilet paper was not tested again, because it was clear that it disintegrates and the result of the one test was satisfactory. The final conclusion is that toilet paper is a welcome product in sewers and is not caught by baskets.

Toilet paper caught by basket | Toilet paper after being dried | Toilet paper not caught

**Figure 5.11. Toilet paper caught by basket**

### 5.4.2 Newspaper and magazine paper

Newspaper and magazine paper showed more or less the same results, therefore they are addressed together. For both these products most was caught by the basket at 0 hours with the basket above and below the water as illustrated with the graphs in Figure 5.12 a&c and Figure 5.13 a&c. This indicates the threat these paper products can be to pump stations by blocking the baskets. If this scenario happens baskets will fill too quickly, which will require more regular maintenance. However, this is the worst case scenario where the products would enter the sewer system just before the pump station, as illustrated by zone 1 in Figure 5.9.

After being in the water for 1 hour, less of the product is caught. The average amount of newspaper caught after 1 hour retention time for the basket above was 149.6g and 166.8g of 250g for the basket halfway submerged. For the magazine paper the average was 145.2g for the basket above and 158.8g for the basket halfway submerged after 1 hour retention time. The baskets caught slightly more of the newspaper than the magazine paper after 1 hour retention time for both heights as presented in Figure 5.12 b&d and Figure 5.13 b&d. This is probably because the magazine paper has a glossy finish. The basket caught slightly less of the products when it was suspended above the water. This result should not be evaluated out of context, since when the basket was halfway submerged the product that escapes the basket still rotates in the sump and was caught on the outside of the basket when it was hoisted. However, if the product remains in the sump for a longer period it would settle to the bottom. This was tested and is addressed in Section 5.5. Figure 5.14 illustrates the newspaper and magazine paper caught by the basket in different scenarios.

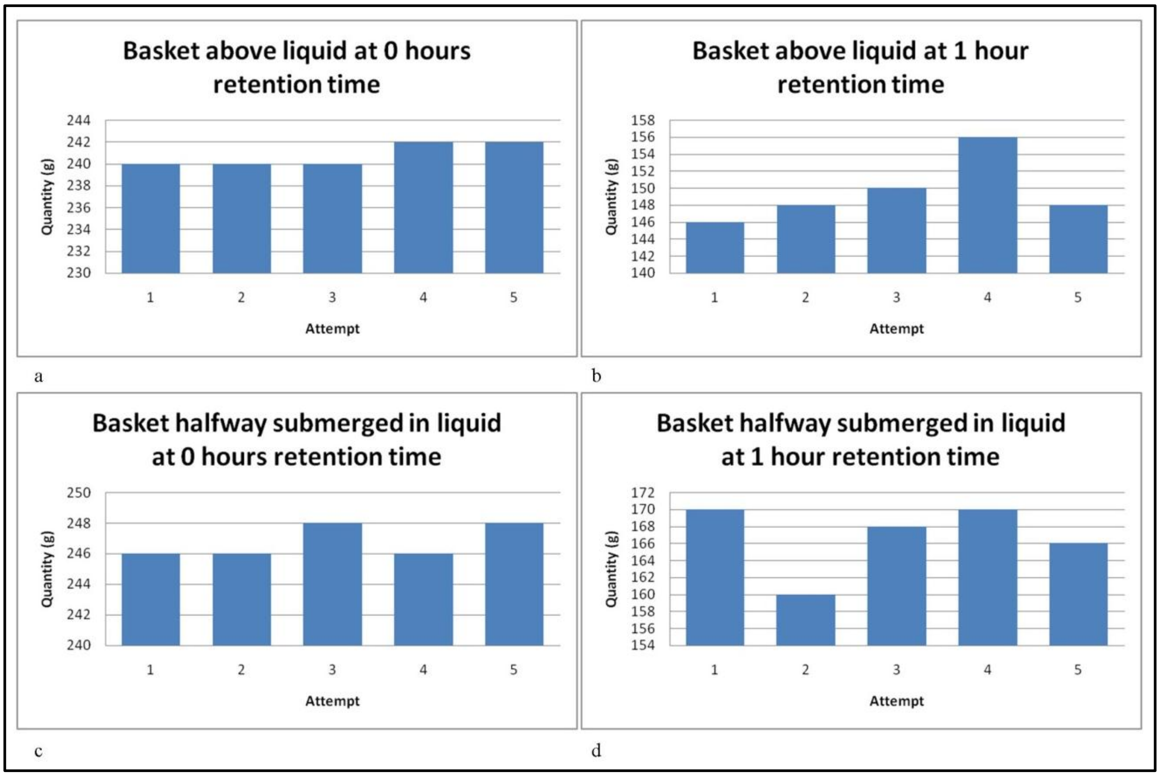



**Figure 5.12. Newspaper test results**

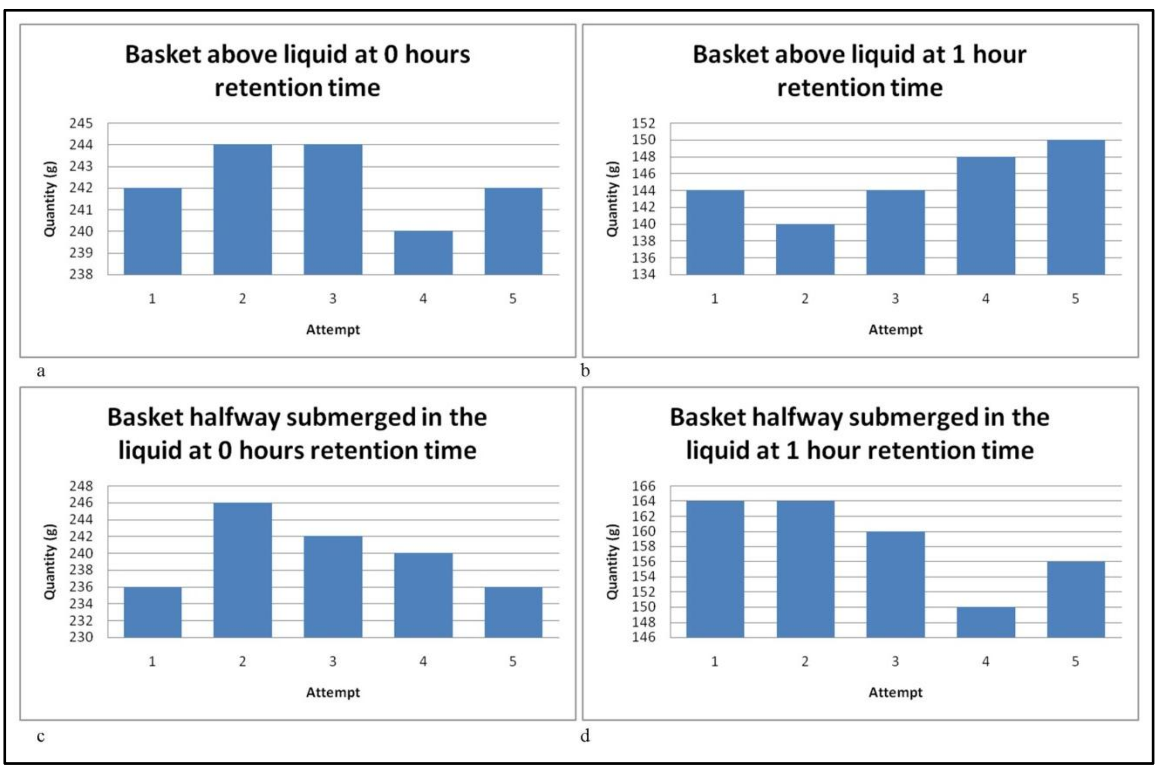



**Figure 5.13. Magazine paper test results**


**Figure 5.14. Newspaper and magazine paper caught by basket**

### 5.4.3 Cotton buds

Cotton buds were reported to be are a major problem; the basket used during tests did not remove them effectively due to the screen spacing of 50mm. Finer spacing would be required to catch cotton buds. When the basket was suspended above the water, the basket caught virtually nothing. With the basket halfway submerged it caught slightly more cotton buds with 0 hours retention time. The basket caught about 21% of the cotton buds on average for the basket submerged after 1 hour retention, as seen in Figure 5.15d. This was due to puffiness of the cotton end of the buds after being in the water for 1 hour. The buds are then more likely to get caught, especially if they are swirling around in the sump while the basket is still submerged. The results of this test are presented in Figure 5.15. Cotton buds pose a problem for sewers, because they have a rigid structure and are not biodegradable. New biodegradable cotton buds are available that have paper stems and sink, where the more usual cotton buds float at first. The stems of the biodegradable buds lose their rigidity after being in a liquid for a while, but they also are not removed effectively by the basket. Figure 5.16 shows the two types of cotton buds and photos of the tests for the not biodegradable cotton buds.

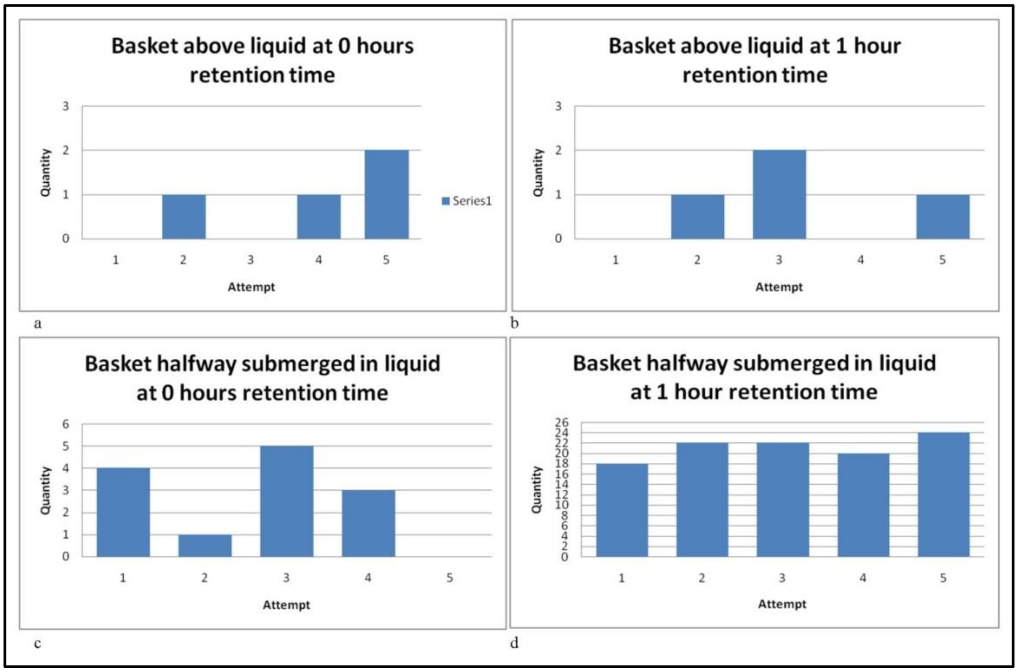



**Figure 5.15. Results for cotton buds (not a biodegradable product)**


Cotton buds products

Puffiness of cotton buds

Cotton buds after 0 hours, basket above

Cotton buds after 1 hour, basket submerged

**Figure 5.16. Cotton buds**

### 5.4.4 Dental floss

The results presented in Figure 5.17c&d indicate that dental floss is almost always caught if the basket is halfway submerged in the water. The results for the basket above the water after 1 hour retention were inconsistent, but on average it caught more of the sample than for 0 hours retention time for the same height. Figure 5.18 presents photos of the results.

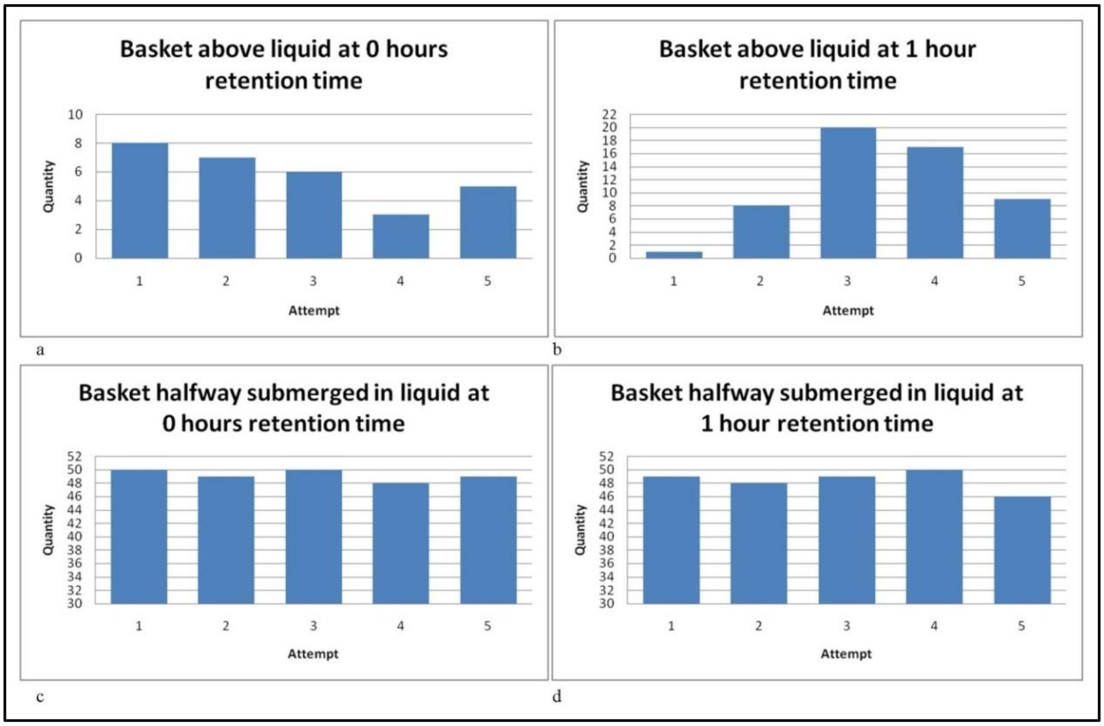
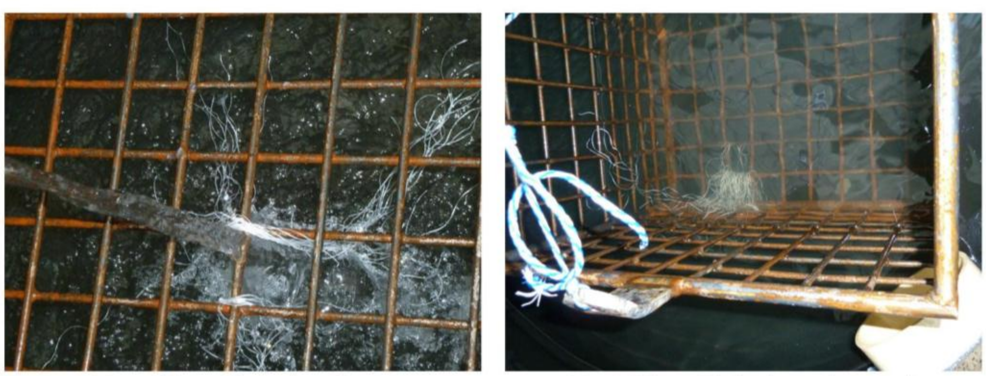



**Figure 5.17. Results for dental floss**



Dental floss 1h, basket above — Dental floss 0h, basket submerged

**Figure 5.18. Dental floss caught by basket**

### 5.4.5 Stockings

The stockings were all caught for every scenario, proving that baskets can effectively remove this threat. The pictures in Figure 5.19 show the stockings caught by the basket.

Stockings after 1h, basket above    Stockings after 0h, basket submerged

**Figure 5.19. Stockings caught by basket**

### 5.4.6 Final tests

Most of the results on the individual items indicate that the basket works better if it is halfway submerged, except for the paper products. In order to get a better result for the paper products two final tests were conducted to see if the paper would disintegrate or settle with time. This was done because baskets are not normally cleaned as soon as they are full, but get cleaned maybe once or twice a day at most. The paper products are also the only products with the exception of biodegradable cotton buds that could disintegrate.

For this test all the products in Figure 5.20 were used, where the plastic, metal and cloth products were placed in the model first and the newspaper and magazine paper were entered last. The test was done twice, once with the basket suspended above the water and the other with the basket halfway submerged in the water. After the products had been inserted in the model the water was kept running for an hour. The water was then turned off and the basket was left overnight (15 hours). The next morning the water was turned on for another hour, after which the results were observed.


**Figure 5.20. Products for final tests**

In each scenario nearly all the non-paper products were caught by the basket. When the basket was above the water, almost all the paper products were caught. The paper also had a chance to dry overnight, so it did not dissolve easily.

When the basket was submerged, only a small amount of paper was caught and the rest disintegrated or settled to the bottom of the sump. This is the ideal scenario, because the basket should not fill up with pumpable products. Both these scenarios are illustrated by Figure 5.21 and Figure 5.22.

Figures 5.21 a & b illustrates the basket above the water with the products. In Figure 5.21c the paper products remaining in the sump are shown. Figure 5.21d indicates the amount of paper products caught by the basket on the right and the products that passed on the left. Thus it is clear that if the basket is operated above the water, the paper products will soon fill it up.

**Figure 5.21. Results for final test (basket above water)**

Figures 5.22 a & b illustrates the basket submerged halfway in the water with the products it caught. In Figure 5.22c the paper products remaining in the sump are shown, which is almost all the paper products. Figure 5.22d shows the number of paper products caught by the basket on the right and the products that passed on the left. This proves that the ideal operating height is when the basket is submerged in the water. The paper products get a chance to dissolve and settle, thus not filling the basket with solids that should otherwise be pumpable.


**Figure 5.22. Results for final test (basket submerged halfway in water)**

It is recommended that the operating height of basket be at the mean depth of the sump or somewhere between the on and off sump levels of the pump. By operating the basket in this way, paper products will be constantly exposed to the liquid in the sump, giving them more chance to dissolve.

# 6. Fuzzy logic based efficiency index

## 6.1 Interpretation of results

The observations made from these experiments and the results obtained are quite simple and can be used effectively. Therefore an efficiency index was determined to indicate the ideal implementation of a screening basket. The forecasting of how efficiently the basket will catch unwanted solids was done with the help of a fuzzy logic concept. The concept of fuzzy logic was implemented and adjusted to interpret the data of each specific scenario.

Fuzzy logic has been used in many sewer-related control components. Ostojin et al. (2011) used fuzzy logic to optimise the energy costs savings at sewage pump stations. A fuzzy control system uses IF-THEN statements and can be created to match any set of input-output data (Murtha, 1995). Fuzzy logic has three components namely the fuzzy sets (system inputs), the IF-THEN rules and the system outputs.

## 6.2 Fuzzy sets

Fuzzy sets are described domains of the inputs, each of which is thought to have a definite effect on the output (Murtha, 1995). The system input parameters can be anything defined by the user; Ostojin et al. (2011) used the change rate of the sump levels over time and the level of sump as the inputs to determine the energy costs savings. Chiang et al. (2010) determined the outputs for an automated control system for sewage pump stations in Taipei city (Taiwan), where the input parameters were water level, precipitation, status of pumps, status of gates and the predictive water level (Chiang et al., 2010).

For this research project the system inputs selected to form part of the fuzzy sets are the height of the basket above the sump water level, the retention time of the solids and the type of solids in the system. The fuzzy sets are presented in Table 6.1. The domains for the height of the basket are either above the water or halfway submerged and similarly for the retention time (0 or 1h) and type of solids (degradable or not).

**Table 6.1. Fuzzy sets**

| Height of basket | Retention time of solids | Type of solids |
|---|---|---|
| Above water | 0h | Not degradable |
| Halfway submerged in water | 1h | Degradable |

### *6.3 Degree of membership*

The values of the system inputs are defined by a degree of membership, where 1 is the most and 0 is the least, as demonstrated in Figures 6.1 to 6.3. These membership degrees are defined by trapeziums, as the effect would change between the domains of fuzzy sets for each domain. The rate of change between the states is described by a linear increase in this case, because the change between the domains was consistent.

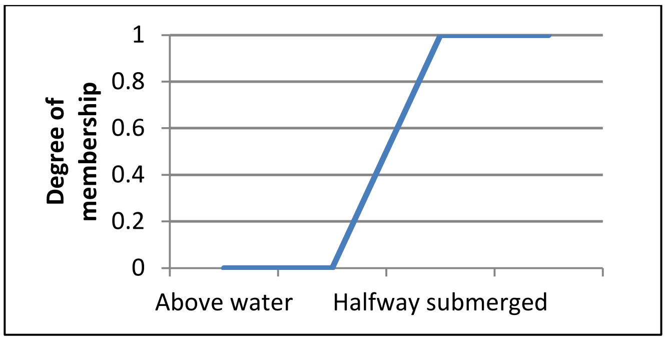



**Figure 6.1. Height of basket**

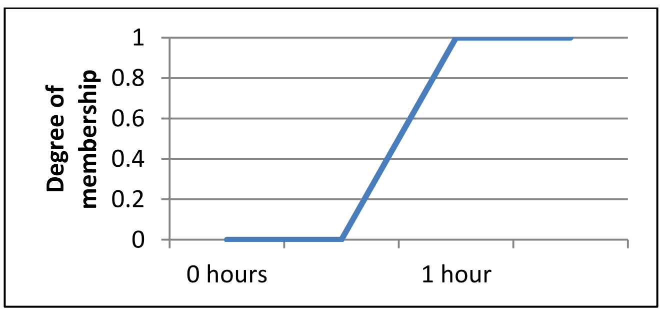



**Figure 6.2. Retention time of solids**

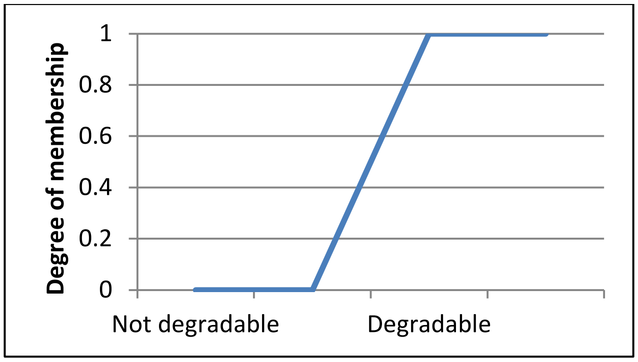



**Figure 6.3. Type of solids**

## *6.4 Possible applications*

### 6.4.1 Developing basic basket efficiency index

There are three inputs with two domains each, that implies that there are a total of eight rules (2x2x2 =8) to be applied. The eight rules are as follows:

1. IF(basket above & 0h & Not degradable) THEN (Basket not at all efficient)
2. IF(basket above & 0h & Degradable) THEN (Basket not efficient)
3. IF(basket above & 1h & Not degradable) THEN (Basket not efficient)
4. IF(basket above & 1h & Degradable) THEN (Basket efficient)
5. IF(basket halfway submerged & 0h & Not degradable) THEN (Basket not efficient)
6. IF(basket halfway submerged & 0h & Degradable) THEN (Basket efficient)
7. IF(basket halfway submerged & 1h & Not degradable) THEN (Basket efficient)
8. IF(basket halfway submerged & 1h & Degradable) THEN (Basket most efficient).

All the domains contribute to efficiency of the basket. Each rule has strength and to determine the strength, the values of all the domains in the rule are combined to create an identifiable index. In some fuzzy systems the minimum or maximum value of any domain used in a rule would be the antecedent for the index. In this scenario the values of the domains are combined to create the efficiency index. The strength of each rule is presented below and the efficiency index is presented in Table 6.2.

1. IF(0,0,0) THEN (0)
2. IF(0,0,1) THEN (1)
3. IF(0,1,0) THEN (1)
4. IF(0,1,1) THEN (2)
5. IF(1,0,0) THEN (1)
6. IF(1,0,1) THEN (2)
7. IF(1,1,0) THEN (2)
8. IF(1,1,1) THEN (3).

**Table 6.2. Efficiency index of basket installations**

| | |
|---|---|
| Basket not at all efficient | 0 |
| Basket not efficient | 1 |
| Basket efficient | 2 |
| Basket most efficient | 3 |

The fuzzy logic model shows that the basket is best operated halfway submerged, after 1h retention time and with degradable solids in the system as identified from the laboratory experiment. This result applies to the experiment that was conducted as part of this research and should not be generalized. However, fuzzy logic also allows for determination of the efficiency of a basket at heights between above and halfway submerged or solids with any retention time between 0 hours and 1 hour. For instance if a basket halfway submerged, with 30 minutes retention time and degradable solids, the rule would be IF (1,0.5,1) THEN (2.5). As soon as the domains are changed, the degree of membership changes and this subsequently impacts the efficiency of the basket.

This efficiency index can only be applied to this scenario of the laboratory experiment, because it would change if the basket was fully submerged or the solids had a retention time longer than one hour. This concept of determining basket efficiencies by means of fuzzy logic could be applied to any basket installation and could in the future be extended to site-installations.

### 6.4.2 Extended laboratory experiment application

The limitations addressed in 5.3.3 are all factors that could have had an impact on the results of the laboratory experiment. These factors could all be tested in an extended laboratory experiment on screening baskets. This section presents the hypothetical results of such a test and how fuzzy logic could be applied to such a test in the future.

The assumptions made to illustrate the fuzzy logic application to an extended laboratory experiment are presented in Table 6.3. The positive and negative effect is only to demonstrate which of the scenarios would be more efficient and less efficient. More variables could be applied to this experiment, but for this example six variables were chosen to illustrate the possible application.

**Table 6.3 Assumptions for extended laboratory experiment application**

| Variables | Scenarios tested | Effect on efficiency of basket | Comments |
|---|---|---|---|
| Height of basket | Above the water | negative | Results from lab test |
| | Halfway submerged in the water | positive | Results from lab test |
| Retention time of solids | 0h | negative | Results from lab test |
| | 1h | positive | Results from lab test |
| Type of solids | Degradable | positive | Results from lab test |
| | Not degradable | negative | Results from lab test |
| Flow rate | Full flowing pipe | positive | Assumption |
| | Half full flowing pipe | negative | Assumption |
| FOG deposits | No FOG deposits | positive | Assumption |
| | FOG deposits | negative | Assumption |
| Distance solids falls before entering basket | 0.5m | negative | Assumption |
| | 1.5m | positive | Assumption |

The possible fuzzy sets with their representative degree of membership are presented in Table 6.4.

**Table 6.4 Fuzzy sets for extended laboratory experiment**

| Height of basket | Retention time of solids | Type of solids | Flow rate | FOG deposits | Distance solids falls before entering basket | Degree of membership |
|---|---|---|---|---|---|---|
| Above the water | 0h | Not degradable | Half full flowing pipe | FOG deposits | 0.5m | 0 |
| Halfway submerged in the water | 1h | Degradable | Full flowing pipe | No FOG deposits | 1.5m | 1 |

There are now six different inputs with two domains each, that implies that there are a total of sixty four rules (2x2x2x2x2x2 =64) to be applied. The first 10 possible rules are demonstrated below:

1. IF(basket above & 0h & Not degradable & Half Full & FOG & 0.5)
2. IF(basket above & 0h & Not degradable & Half Full & FOG & 1.5)
3. IF(basket above & 0h & Not degradable & Half Full & No FOG & 0.5)
4. IF(basket above & 0h & Not degradable & Half Full & No FOG & 1.5)
5. IF(basket above & 0h & Not degradable & Full & FOG & 0.5)
6. IF(basket above & 0h & Not degradable & Full & FOG & 1.5)
7. IF(basket above & 0h & Not degradable & Full & No FOG & 0.5)
8. IF(basket above & 0h & Not degradable & Full & No FOG & 1.5)
9. IF(basket above & 0h & Degradable & Full & No FOG & 0.5)
10. IF(basket above & 0h & Degradable & Full & No FOG & 1.5)

A total of 64 IF statements could be applied to this hypothetical scenario of testing. Each domain would have a value of either zero or one with each IF statement. These values would then be added to get a representative value for each rule. An efficiency index could be developed for this extended laboratory experiment in the same way it was done with for the actual laboratory experiment in Section 6.4.1. The more variables added to the experiment the more complex the fuzzy logic becomes.

### 6.4.3 Fuzzy logic applied to the 4 Os of pump stations

The fuzzy logic concept could be applied to the 4 Os of pump stations. Most of the problems that occur at pump stations occur in conjunction with one another. For instance unwanted objects could lead to many problems like blockages and pump damage. If a blockage occurs the result may be an overflow and an overflow might also result in odours. A value could be given to a problem occurring at pump stations and this could be done with fuzzy logic. This could allow for rating the significance of the problems or the damaging effect.

This application of fuzzy logic will be demonstrated on Overflows, one of the 4 Os of pump station problems presented in Section 4.3.1. To give each individual cause of a problem a value, Plugh's method was used to give each cause a weight (Ullman, 1992) (Jacobs, 1997). Each cause is described as a criterion and is given a weight. Each criterion is weighed against each other with a rating from 1-10. The criterion with higher importance gets a higher score. The cause with the highest score is considered as the cause with the most damaging effect. Overflows have six main categories of causing overflows, namely: blockages, mechanical failures, electrical failures, peak flows, power outages and storage failure. Each of these causes have sub causes (the root of the problems) and these sub causes were scored using Plugh's method as demonstrated in Table 6.5 - 6.10.

**<u>Blockages</u>**

The following criteria were used for blockages:

1. Screens and baskets not cleaned
2. Unwanted objects
3. FOG deposits
4. Grit accumulation

**Table 6.5 Blockages criteria weights**

| **Criteria for comparison** | **1** | **2** | **3** | **4** |
|---|---|---|---|---|
| **1** | * | 7 | 6 | 5 |
| **2** | 3 | * | 4 | 4 |
| **3** | 4 | 6 | * | 6 |
| **4** | 5 | 6 | 4 | * |
| **Weight** | **12** | **19** | **14** | **15** |

The following values are given to the criteria's to apply it to fuzzy logic:

- Screens and baskets not cleaned = 1
- FOG deposits = 2
- Grit accumulation = 3
- Unwanted objects = 4

The criteria with the lowest weight will have the least damaging effect and therefore are given the lowest scoring value. All causes are scored from the value of one up to the most damaging cause in increments of one. This technique was applied to all the causes as presented below.

**Mechanical failures**

The following criteria were used for mechanical failures:

1. Design deficiencies
2. Unwanted objects
3. Parts failure
4. Wear and tear
5. Lifetime complete

**Table 6.6 Mechanical failure criteria weights**

| Criteria for comparison | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1 | * | 7 | 6 | 4 | 4 |
| 2 | 3 | * | 5 | 4 | 3 |
| 3 | 4 | 5 | * | 4 | 4 |
| 4 | 6 | 6 | 6 | * | 6 |
| 5 | 6 | 7 | 6 | 4 | * |
| **Weight** | **19** | **25** | **23** | **16** | **17** |

The following values are given to the criteria's to apply it to fuzzy logic:

- Wear and tear = 1
- Lifetime complete = 2
- Design deficiencies = 3
- Parts failure = 4
- Unwanted objects = 5

**Electrical failure**

The following criteria were used for electrical failures:

1. Wiring
2. Level probes failure
3. Failure of alarm, telemetry or monitoring equipment
4. Switching failure

**Table 6.7 Electrical failure criteria weights**

| Criteria for comparison | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | * | 4 | 3 | 4 |
| 2 | 6 | * | 4 | 5 |
| 3 | 7 | 6 | * | 7 |
| 4 | 6 | 5 | 3 | * |
| **Weight** | **19** | **15** | **10** | **16** |

The following values are given to the criteria's to apply it to fuzzy logic:

- Failure of alarm, telemetry or monitoring equipment = 1
- Level probes failure = 2
- Switching failure = 3
- Wiring = 4

**Peak flows**

The following criteria were used for peak flows:

1. Vacation period
2. Stromwater ingress
3. Illegal linkage
4. Swimming pool overflows

**Table 6.8 Peak flow criteria weights**

| Criteria for comparison | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | * | 6 | 5 | 3 |
| 2 | 4 | * | 4 | 3 |
| 3 | 5 | 6 | * | 4 |
| 4 | 7 | 7 | 6 | * |
| **Weight** | **16** | **19** | **15** | **10** |

The following values are given to the criteria's to apply it to fuzzy logic:

- Swimming pool overflows = 1
- Illegal linkage = 2
- Vacation period  = 3
- Stromwater ingress = 4

**Power outages**

The following criteria were used for power outages:

1. Supply failure
2. Generator failure
3. Cable theft
4. Switching failure

**Table 6.9 Power outages criteria weights**

| Criteria for comparison | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | * | 6 | 6 | 4 |
| 2 | 4 | * | 4 | 3 |
| 3 | 4 | 6 | * | 4 |
| 4 | 6 | 7 | 6 | * |
| **Weight** | **14** | **19** | **16** | **11** |

The following values are given to the criteria's to apply it to fuzzy logic:

- Switching failure = 1
- Supply failure = 2
- Cable theft = 3
- Generator failure = 4

**<u>Storage failure</u>**

The following criteria were used for storage failure:

1. Inflow>outflow
2. Not sufficient emergency storage in sump
3. Structural failure
4. Inadequate overflow facilities

**Table 6.10 Storage failure criteria weights**

| Criteria for comparison | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | * | 4 | 4 | 4 |
| 2 | 6 | * | 4 | 4 |
| 3 | 6 | 6 | * | 6 |
| 4 | 6 | 6 | 4 | * |
| **Weight** | **18** | **16** | **12** | **14** |

The following values are given to the criteria's to apply it to fuzzy logic:

- Structural failure = 1
- Inadequate overflow facilities = 2
- Not sufficient emergency storage in sump = 3
- Inflow>outflow = 4

The value of each sub cause is now considered to be the degree of membership of each individual cause. The six main causes were also weighed against each other and are presented in Table 6.11.

The following criteria were used for the main causes of overflows:

1. Blockages
2. Mechanical failures
3. Electrical failures
4. Peak flows
5. Power outages
6. Storage failure

**Table 6.11. Main causes of overflows criteria weights**

| **Criteria for comparison** | **1** | **2** | **3** | **4** | **5** | **6** |
|---|---|---|---|---|---|---|
| **1** | * | 3 | 3 | 4 | 4 | 5 |
| **2** | 7 | * | 5 | 6 | 6 | 7 |
| **3** | 7 | 5 | * | 6 | 5 | 6 |
| **4** | 6 | 4 | 4 | * | 4 | 6 |
| **5** | 6 | 4 | 5 | 6 | * | 6 |
| **6** | 5 | 3 | 4 | 4 | 4 | * |
| **Weight** | **31** | **19** | **21** | **26** | **23** | **30** |

The following values are given to the main criteria's to apply it to fuzzy logic:

- Mechanical failures = 1
- Electrical failures = 2

- Power outages =3
- Peak flows = 4
- Storage failure =5
- Blockages =6

The main causes of overflows can now be considered as the fuzzy sets for overflows. Each fuzzy set now has a representative value. The fuzzy sets with their degrees of membership are presented in Table 6.12.

**Table 6.12 Fuzzy sets for overflows**

| Blockages | Mechanical failures | Electrical failures | Peak flows | Power outages | Storage failure | Degree of membership |
|---|---|---|---|---|---|---|
| Screens and baskets not cleaned | Wear and tear | Failure of alarm, telemetry or monitoring equipment | Swimming pool overflows | Switching failure | Structural failure | 1 |
| FOG deposits | Lifetime complete | Level probes failure | Illegal linkage | Supply failure | Inadequate overflow facilities | 2 |
| Grit accumulation | Design deficiencies | Switching failure | Vacation period | Cable theft | Not sufficient emergency storage in sump | 3 |
| Unwanted objects | Parts failure | Wiring = 4 | Stromwater ingress | Generator failure | Inflow > outflow | 4 |
| | Unwanted objects | | | | | 5 |

Fuzzy logic could now be applied to any problem as described with the following example. If an unwanted object is at the pump station it might lead to blockages or mechanical failures, but the damaging effect will differ in severity depending on the result. This damaging effect can now be rated or ranked by applying fuzzy logic. The fuzzy sets now have their own degree of membership, this membership will be multiplied with the degree of membership of the sub causes giving each cause of overflows a value. This method is explained with the IF statements and corresponding values.

IF (blockage due to unwanted object) THEN (6 x 4) = 24

IF (mechanical failure due to unwanted object) THEN (1 x 5) = 5

This indicates that if an unwanted object causes a blockage the effect will be greater than for a mechanical failure. This could be a true representation of the severity of the problem, because if a mechanical failure occurs, the back-up pump will most likely be used and the sump should have emergency storage or overflow facilities could be utilised. However if a blockage occurs in the inlet to the pump station, an overflow will occur very quickly; therefore it has a higher possibility of damaging effect, because an overflow could occur almost immediately. Where with the mechanical failure it might take a while before an overflow will occur. With the mechanical failure there is still time to fix the problem before a overflow would occur

Another example could be the following:

IF (power outage due to supply failure) THEN (3x2) = 6

This method of applying fuzzy logic could be applied to all 4 Os of pump station problems. This however is only a hypothetical scenario approach. In practise this approach should be taken with more detail and specifics.

# 7. Decision Support Tool Concept

## 7.1 Overview

The pumping of sewage poses various problems, complicating decision making during the design as well as the operation and maintenance phases of the pump station life cycle. An interactive DST concept was developed as part of this research to assist with pump station design and understanding. Pump stations form critical components in most sewer systems and pose many challenges and present hazards to municipalities responsible for their operation and maintenance.

The idea of developing a DST was to assist designers, operators and students with understanding of and problem identification for sewage pump stations in the future. The DST presented in this research is only the concept tool for such a DST. The DST in this study is should not be used as a final product for problem identification or design guidance. This DST could only be used as the basis for a concept DST to be developed further for more proper usage. The DST is only the formwork for a potential full functioning DST in the future. The idea for this DST for sewage pump stations was taken from the SewerAID concept (van Vuuren & van Dijk, 2011). The content for the DST was all taken from the literature presented, the problems identified and the pictures taken at site visits. The idea was to develop a tool that would act as a visual aid for sewage pump stations problems and guidance for sewage pump station designs. This study proposes a concept design of a DST that focuses on sewage pump stations alone. The tool provides further background information, photos and additional literature to aid with the understanding of sewage pump stations problems, with a specific focus on removing solids. This tool would be an indirect solution to some existing problems and would help to avoid future problems. The DST developed and presented in this chapter was also submitted to the WRC for a related project (Jacobs et al., 2011).

## *7.2 Development of DST*

The DST comprises two main sections, namely the design aid section and the problem aid section. The literature on pump stations (Chapter 2) and solids in sewers (Chapter 3) were used as the backbone of the design aid section. The problems identified in Chapter 4 were the basis of the problem aid section of the DST.

The DST allows the user to focus on any one particular section of the pump station at a time. Many different components were integrated with the design of the DST. Pump station components included in the DST are the inlet works, sump, pumps, electrical equipment and structural elements, to name but a few. The DST features all the different sections of a pump station, providing various design options in each case. The DST allows for interactive graphic illustrations of possible design components, related problems and literature resources, providing useful information in a structured and convenient way. The tool can also be used as a sewage pump station problem identification tool. This DST would be of value to engineering consultants, service providers and educational institutions.

This DST is only a prototype concept version. This prototype concept can be used as the basis for the design of a fully functioning DST. A program was designed to illustrate the functioning of this DST. The program was developed in MS Excel with a user friendly visual interface and is very easy to operate and is self-explanatory. The DST requires no user inputs, apart from clicking to obtain the required output text and photos, and no mathematical calculations are conducted in the process.

The focus of the tool is mostly on sewage pump station problems and the inlet works of the pump station, since that is where solids removal takes place. The other sections of the pump station are only addressed briefly for the purpose of this prototype DST.

### 7.2.1 Design aid section

The design aid section allows the user to view the different sections of a pump station with different design options in each section. The station sections used for the DST are the same sections as presented in Figure 2.1, where each section has visual aids such as drawings or photos of existing examples in the field. The design section also presents additional literature to aid with further research. The diagram presented in Figure 7.1 illustrates the bodywork and mind map of the DST, where inlet works are addressed in more detail, since it is the focus of this report. The application of the design aid section is addressed in Section 7.3.1.

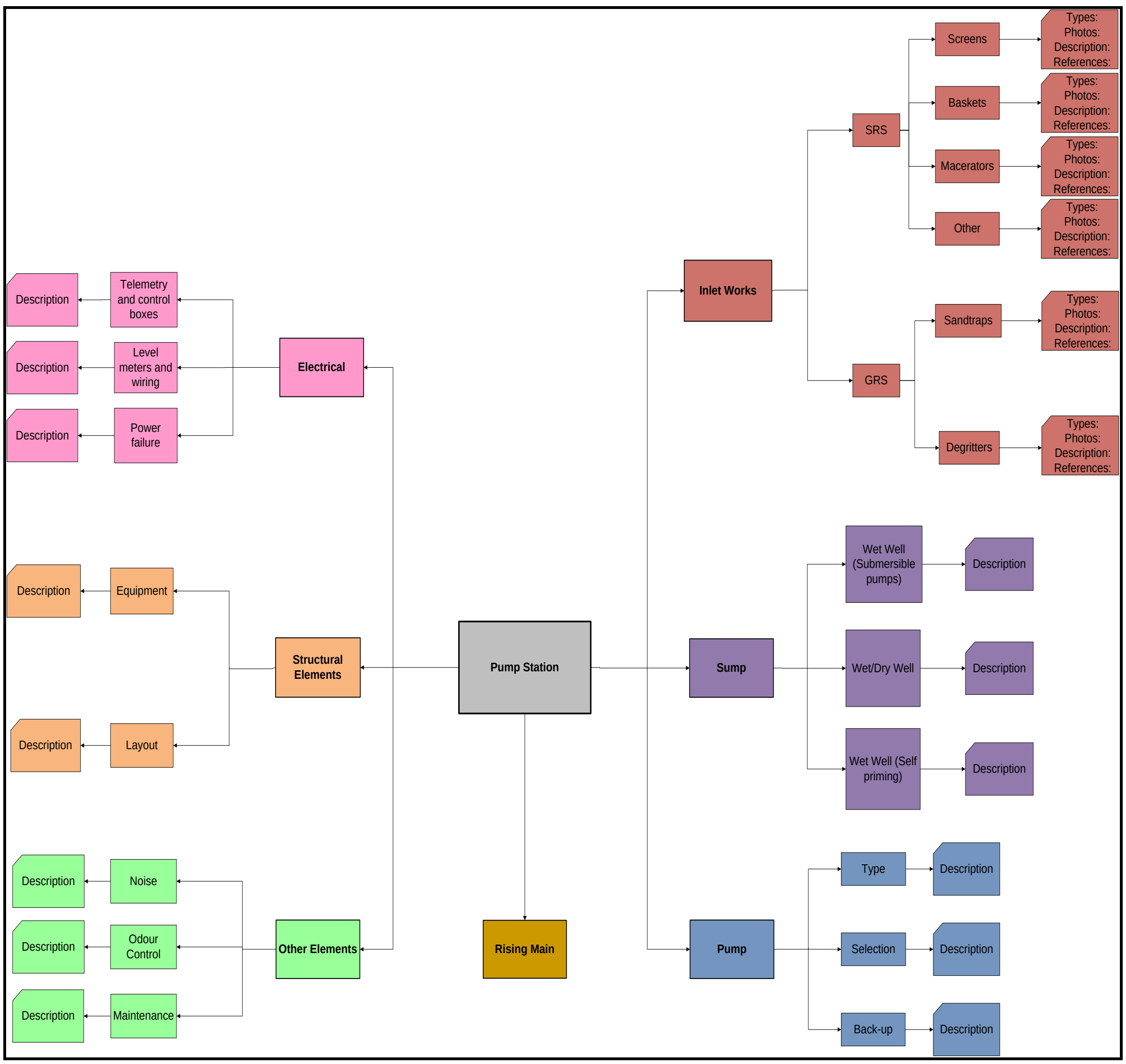



**Figure 7.1. Bodywork of design aid section**

### 7.2.2 Problem aid section

The problem aid section helps the user to identify potential problems or problems that have occurred. The 4 Os of pump station problems were used in the DST to aid with problem identification. The user selects one of the four problems and the causes of the problem are presented, assisting the user to identify why or how certain problems occurred. The organization charts from Figures 4.7 to 4.10 which illustrate the problems and their causes, are used in the problem aid section of the DST.

### 7.2.3 Target user

#### *7.2.3.1 Main users*

A wide range of users have been targeted for the purpose of this DST. The main users would be service providers that deal with sewage pump stations and its corresponding problems on a regular basis. This means that municipalities would be the main target user for the application of this DST. The typical breakdown of the users at municipalities is explained and the application of the DST is demonstrated with Figure 7.2. The users could be any of the following:

**Technical staff (labourers)**
This is the group of users responsible for the maintenance of the pump stations, they maintain the pump stations and do the cleaning of the baskets and screens. This is the representative team working on the ground and doing all the dirty work. This group of people usually have very little education and their abilities are limited to physical work.

**Maintenance manager**
This is normally the person who is in charge of all the labourers and the workshop. This person normally has more knowledge on pump stations and would be the contact person if a problem should occur.

**Section/Operational manager**
This person would be in charge of all the operations at a municipality or section of a municipality. The maintenance manager would report to the section manager.

**Engineer**

The engineer overlooks all the activities and all personnel would report to the engineer. The engineer is supposed to be the one with the most knowledge on sewage pump stations.

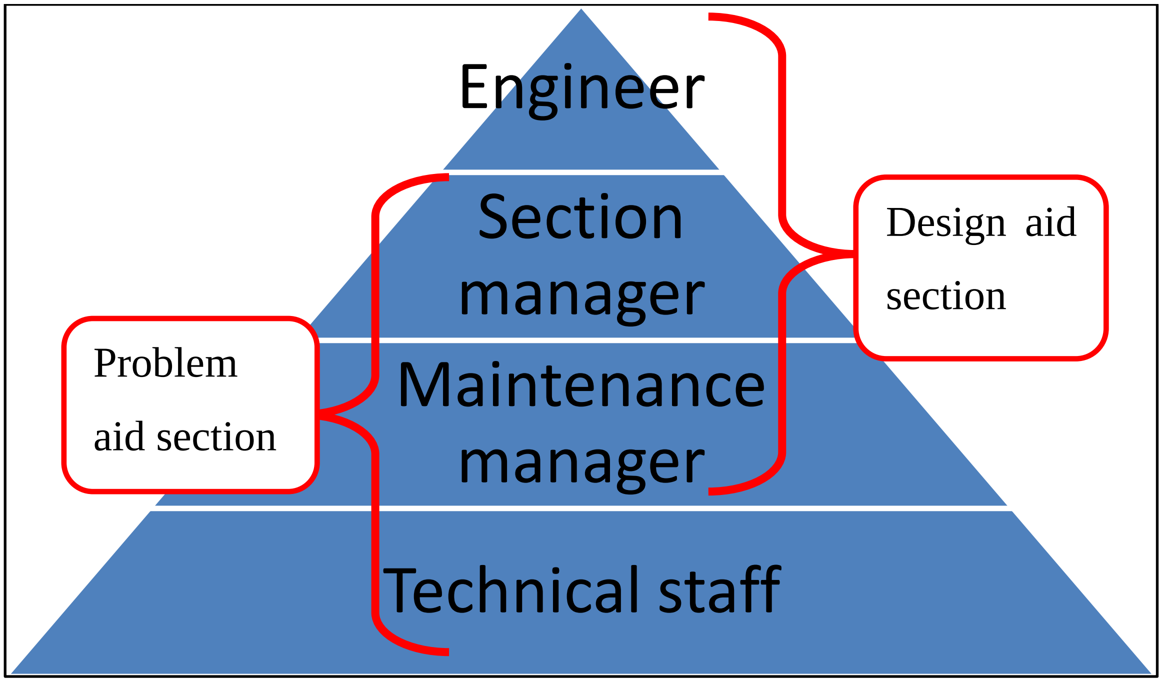



**Figure 7.2 Target users for DST**

The DST could be used as a communication tool between the different involved parties. For instance the maintenance manager can point out problematic areas or short comings in different components of the pump station using the DST. The engineer can then gather more information referring to the literature sources listed in the DST.

### *7.2.3.2 Alternative users*

Alternative users could include educational institutions such as Universities. The tool can be handed out to students for further guidance on sewage pump stations with useful illustrations and literature. The DST serves as a good summary of all the sewage pump station components and problems.

Researchers in the research field could also be target users. The DST is a helpful tool to get the right knowledge about sewage pump stations to the people who might want or need it.

#### *7.2.3.3 Future users*

If the tool are expanded and further developed to contain proper design guidance, a target user could be designers. The tool could then assist designers with codes and guidelines for design purposes.

## *7.3 Application of DST*

The aim was to keep the tool uncomplicated, with limited inputs and maximum knowledge being provided in a structured way. This section has addressed the use of the DST and explained examples of its use. The DST is very easy to use and self-explanatory (provided that the user clicks on the title tabs and not the photos), but this section serves as a user manual. In order to use the file, MS Excel must be available and all macros should be enabled. To execute the DST, simply open the file attached on the CD in Appendix F named:

"Sewage Pump Station Design and Problem Aid 0.1.xlsm"

### 7.3.1 Application of design aid

The program is opened with Excel and once it is open the user can select one of two modes. Either the Sewage Pump Station Design Aid or the Sewage Pump Station Problem Aid can be selected, as depicted in Figure 7.3. In this hypothetical scenario the design aid was selected and Figure7.3 illustrates what the user sees on opening the program and then selecting the design aid mode marked in red.

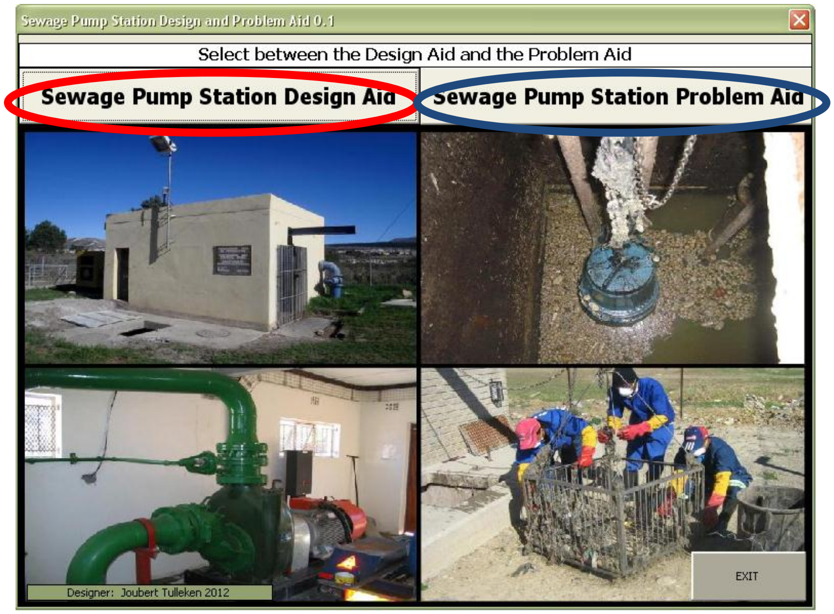



**Figure 7.3. DST opening screenshot**

Consider the example where the user wants to know more about screening techniques, then *Inlet Works* would be selected. Figure 7.4 shows the different sections of the pump station, which the user is able to select. The user selected the Inlet works as presented in Figure 7.4.

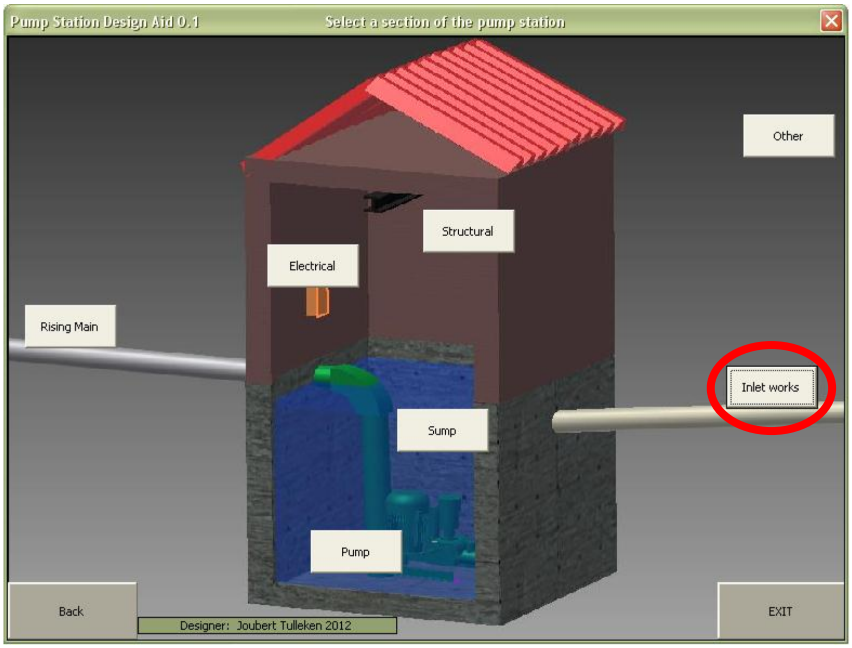



**Figure 7.4. Selecting a pump station section**

The user selected *Inlet Works* and different technologies for removing solids are presented in Figure 7.5. Each technology has a description and can be selected for supplementary details regarding the specific technology. In this hypothetical scenario the user selected *Screening* option as presented in Figure 7.5.

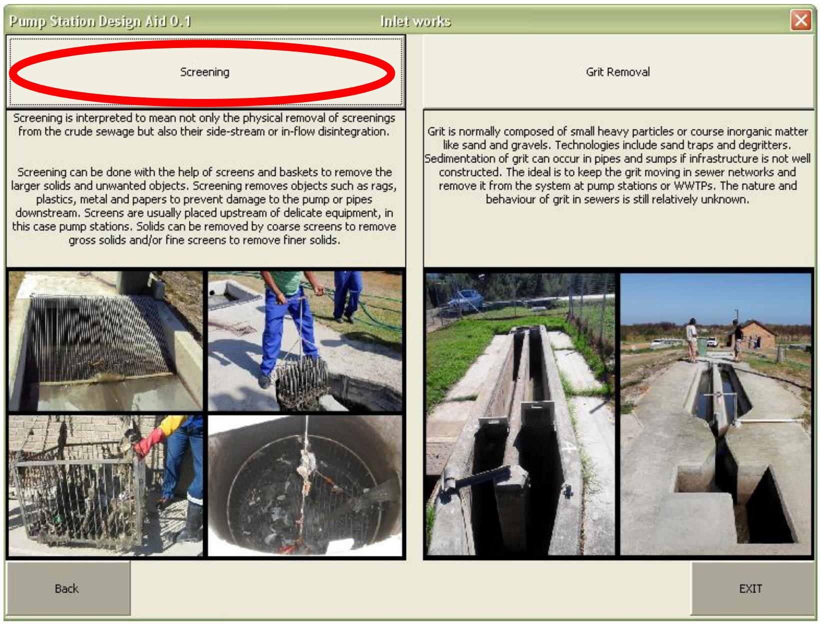



**Figure 7.5. Inlet works technologies**

The user is now presented with different screening techniques with descriptions and is able to select any screening method to see photos of examples. Supporting literature on screening is also presented. Figure 7.6 illustrates the different screening techniques and user selected *Baskets* for further information.

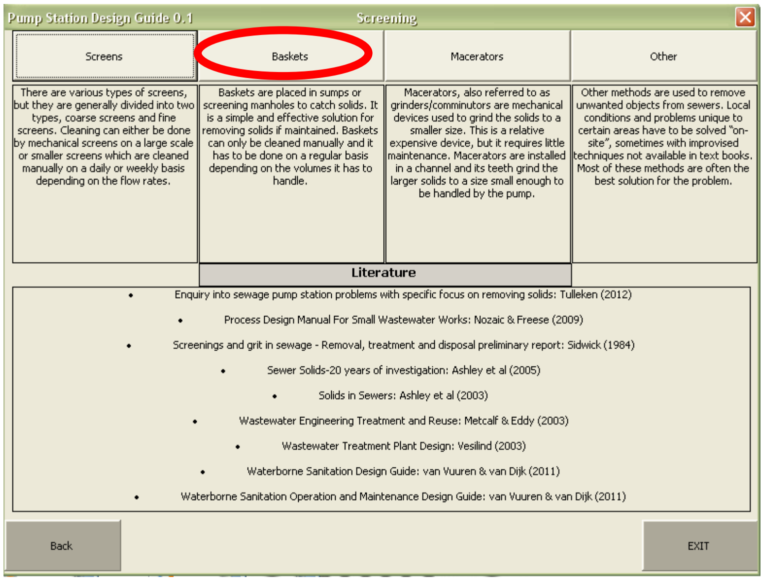



**Figure 7.6. Possible screening techniques**

After *Baskets* is selected, different photos of baskets and basket installations are presented to the user, which is illustrated in Figure 7.7.


**Figure 7.7. Baskets and basket installations**

The user can go back to a previous screen at any time to select a different option or exit the program.

### 7.3.2 Application of problem aid

To explain the use of the problem aid a hypothetical scenario was created. For instance, an overflow occurred at a pump station and the cause of the problem should be identified. As soon as the overflow occurs, the operator or ground team can use the DST to identify the cause of the problem. This cause identification is illustrated with Figures 7.8 to 7.11. Once the DST is opened the sewage pump station problem aid can be selected as marked with blue in Figure 7.3.

After selecting the problem aid four possible problems with descriptions are presented, any of the problems can be selected to identify the cause of that specific problem. The four possible problems were identified and addressed in Chapter 4. In this hypothetical case *Overflows* was selected as presented in Figure 7.8.

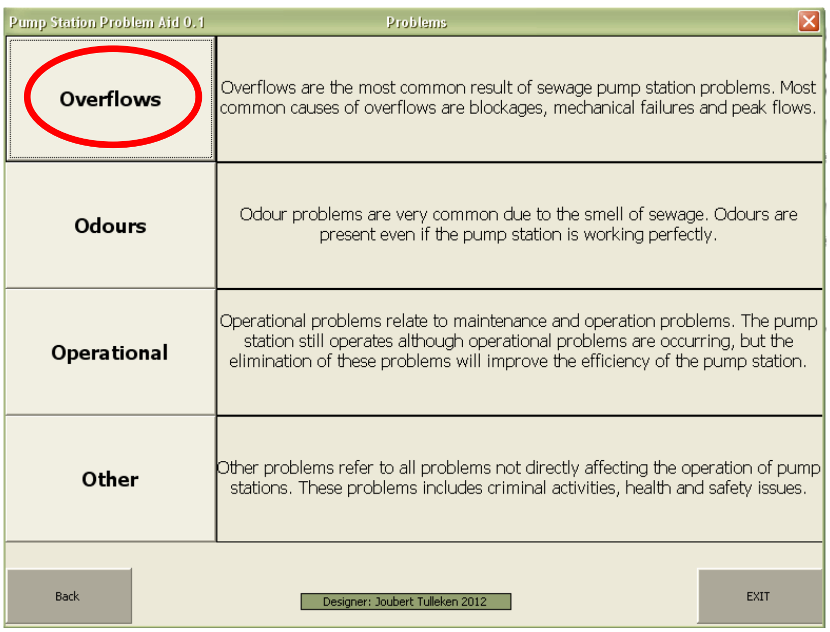



**Figure 7.8. Four possible problems for selection**

Once *Overflows* are selected possible causes for the overflows are presented. The user now knows where to start looking for the cause of the problem. The possible causes are presented in Figure 7.9. All possible causes presented in Figure 7.9 are the same as in Section 4.2 of this report.


**Figure 7.9. Possible causes of overflows**

Hypothetically the user identifies the problem as a power outage as depicted in Figure 7.9. Now the user can select *Power outages* to identify the possible cause of the power outage. Figure 7.10 presents the possible causes of Power outages.

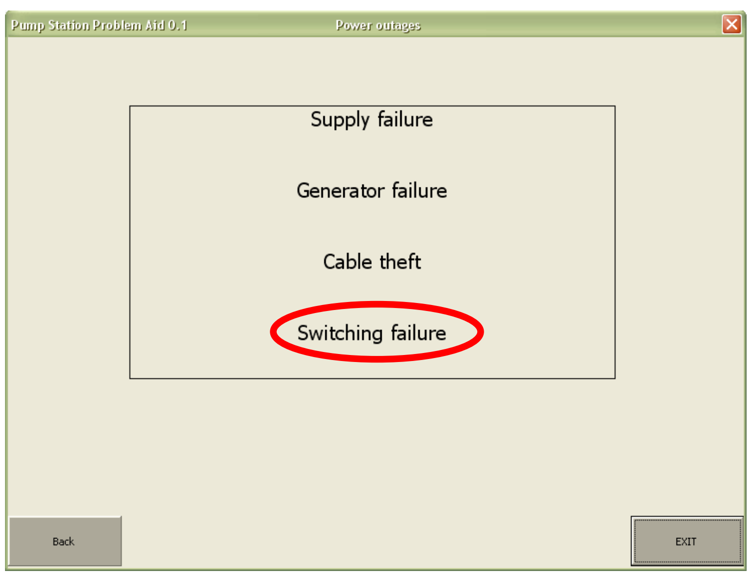



**Figure 7.10. Possible causes of power outages**

The user now hypothetically identifies the problem as a switching failure.

# 8. Conclusion

## 8.1 Overview

Sewage pump stations will always pose problems, with even the newest technologies; that is just a consequence of working with sewage. The various problems and technologies associated with sewage pump stations were investigated and the main findings are summarised in this chapter.

## 8.2 Main findings

Unwanted objects are one of the major problems in the Western Cape sewers, leading to sewage pump station problems and subsequent overflows.

Maintenance of a pump station is an occupational hazard and all municipalities have problems with maintaining pump stations, while some handle the problems better than others. There is room for improvement in many cases regarding the management of employees and municipalities need to learn from each other to achieve better productivity.

Most problematic solids originate from humans abusing sewers. There is a major need for educational programmes to teach people how to use sewers and particularly how to use the toilet, which allows entry to relative large solids of up to about 100mm.

The use of screening devices needs to be encouraged; they are robust, easy to fix and low level skills are required to operate them. Even if advanced solids handling pumps were to be used, the pump life would be extended by employing a SRS (Worthington-Smith, 2011). Pump stations need regular maintenance checks and the cleaning of screens and baskets can be done in conjunction with this operation since cleaning screens and baskets does not take long.

Baskets can operate efficiently if they are cleaned regularly. The recommended operating height for baskets is to have the basket halfway submerged in the sump to give degradable products the chance to disintegrate or dissolve.

The development of more visual aids, such as the DST developed for this study, should be encouraged to assist designers and students at educational institutions.

## *8.3 Future research and recommendations*

There is room for further research in South Africa and the following research areas may require further attention.

People generally have a poor knowledge of how their sanitary textiles should be discarded. They often throw them into the toilets instead of disposing of them with their household waste (Le Hyaric et al., 2009). Techniques for informing or educating the public are required to improve the general public's knowledge on what to dispose of in toilets.

Simulations of flow patterns and the transport of associated pollutants can be simulated with computational fluid dynamics (CFD)-based software tools (Stovin et al., 2008). CFD models were not addressed in this study, but it is recommended that further research be done on CFD models and simulations in order to gain knowledge on how solids behave in sewers.

Studies are required to determine the risk and costs optimisation for pump stations with and without SRSs. The concept for such a possible study is illustrated with Figure 8.1.

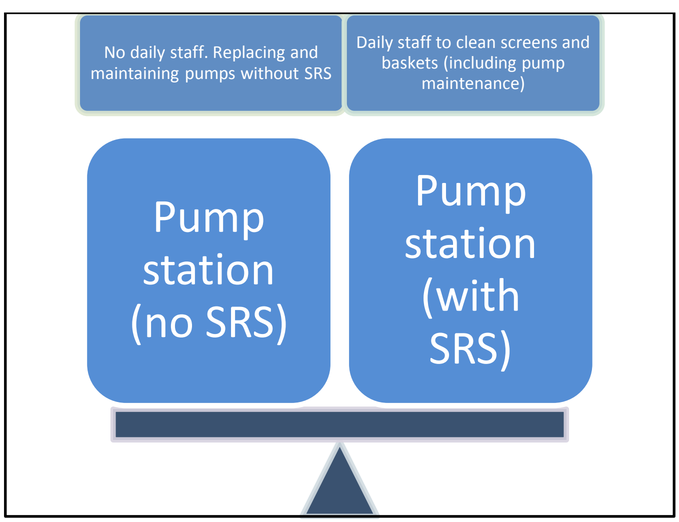



**Figure 8.1. Cost comparison scale**

The tests conducted in the laboratory indicated that the basket should be operated at a level where it is submerged in the sump. Unfortunately this study did not allow for this theory to be implemented on an actual basket in practise. It is recommended that tests are done on a screening basket in practise to confirm or differ from the results obtained from this laboratory experiment. The laboratory test could be extended to also address a SRS in combination with solids handling pumps and the implementation of the combination setup in practice.

### *8.4 Final conclusion*

Problematic areas with shortage in financial backing exist and where municipalities are trying to supply more people with sanitary services, shortcuts have to be made to reach the goal of basic sanitation for all. This is unfortunate and the lack of efficient infrastructure is the result. With more available capital decent pump stations can be constructed with a longer lifetime and better operating conditions with less maintenance. It is the responsibility of engineers to design efficient technologies and come up with more innovative ideas to handle solids at pump stations.

Solids can either be removed at pump stations or at the WWTPs, the remaining question is which of these philosophies is the best. This study focused on removing solids at pump stations and after investigations and tests were completed it was clear that both these philosophies pose problems and it comes down to the authority's preferences. Every sewer is unique and poses its own distinctive problems and therefore each scenario has to be evaluated individually. SRSs are easy to maintain and it is a cheap primary defence against unwanted objects, therefore it is recommended that SRSs be used to minimise the problems at sewage pump stations.

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# *Appendix A Pumps and Pump Installations*

Submersible pump hoisted for routine maintenance, left, and immersible pumps, on the right

Self priming pump in photo above


Odour control system

# *Appendix B Different Types of Screens*

Three coarse screen installations and a mechanically cleaned screen (Nozaic & Freese, 2009)

Coarse screen at pump station in Grabouw

# *Appendix C Field Questionnaire*

| Pump station questionnaire | | |
|---|---|---|
| | Date: | |
| **Pump Station** | | |
| Name | | |
| Location | | |
| GPS coordinates | | |
| | | |
| **Pump Operating data:** | | |
| Type | | |
| Capacity (Motor rating) | | kW |
| Flow Capacity (Q) | | $m^3$/h or l/s |
| Discharge head | | m |
| Number of units per station | | |
| Series or Parallel pumps | | |
| Time in service | | Years |
| Back-up/standby pumps | | Number of pumps |
| Generator | | |
| | | |
| **Flow rates** | | |
| Daily average | | $m^3$/h or l/s |
| Daily peak | | $m^3$/h or l/s |
| Wet weather daily average | | $m^3$/h or l/s |
| Wet weather daily peak | | $m^3$/h or l/s |
| | | |
| **Sump size** | | |
| Volume | | $m^3$ |
| Overflow time | | h |
| | | |
| **Well type** | | |
| Wet/Dry or Single Wet well | | |
| Sand traps/Grit removal | | Yes/No |
| Baskets/Screens | | Yes/No |
| Screens’ gap size | | mm |
| | | |
| **Maintenance** | | |
| Pump Station Visit Intervals | | (weekly, daily) |
| Maintenance frequency | | (monthly, yearly) |
| Log Sheets available | | Yes/No |
| | | |

| **Pump failure** | |
|---|---|
| Frequency of Breakdown | |

| **Constant Problems and Comments** |
|---|
| |

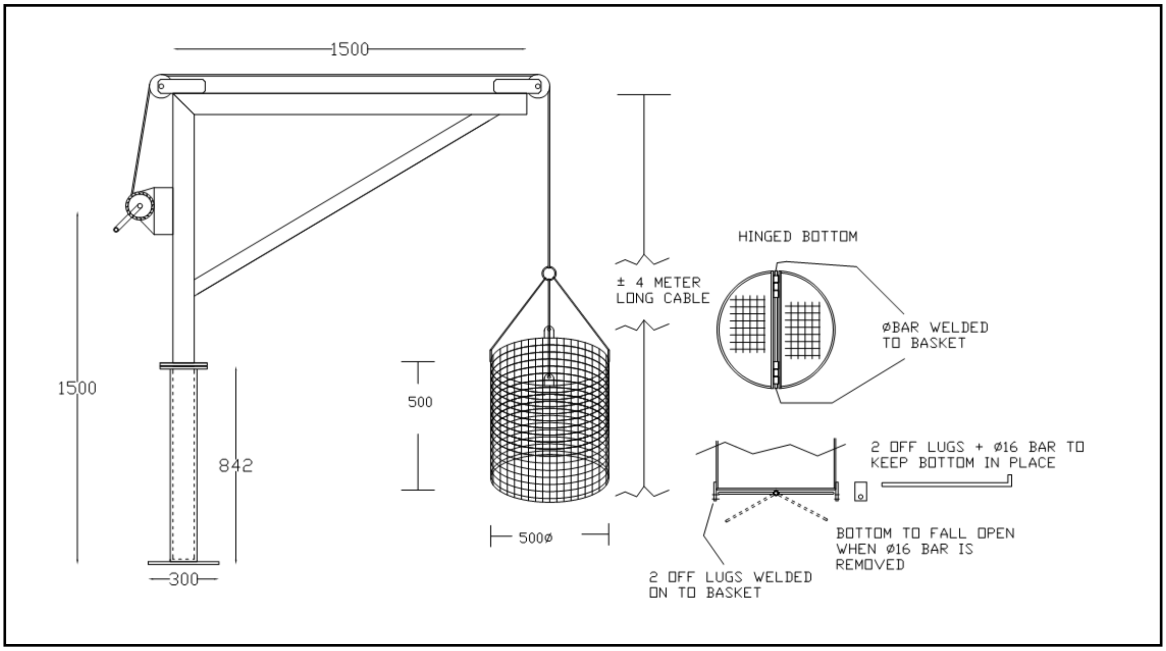
# *Appendix D Site Visits Data Sheet*

| Number | Date of visit | Local authority | Location | Name of pump station | Duration (h) | Project team members | Contact person | Contact details | Visits successful | Notes |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 08/04/2010 | Theewaterskloof | Grabouw | Unknown | 1 | Joubert Tulleken<br>Nouri Koedam | Gert Engelbreght | 0218592507 | YES | Low income housing developments are problematic<br>Foreign objects in system |
| 2 | 08/04/2010 | Theewaterskloof | Genadendal | Unknown | 1 | Joubert Tulleken<br>Nouri Koedam | Denvor Damons | 0798843625 | YES | Low level of maintenance<br>Inefficient cleaning of baskets<br>General area around pump station is dirty<br>Plenty of sand in system |
| 3 | 08/04/2010 | Theewaterskloof | Genadendal | Genadendal WWTP | 1 | Joubert Tulleken<br>Nouri Koedam | Denvor Damons | 0798843625 | YES | Low level of maintenance<br>Operators lack knowledge |
| 4 | 2010/11/08 | City of Cape Town | Zandvliet | Zandvliet WWTP | 2 | Joubert Tulleken<br>Erena Myburg | Deiniol Walker<br>Conrad Newman | dwalker@wssa.co.za<br>cnewman@wssa.co.za | YES | Lift station before treatment works, odour control |
| 5 | 10/09/2010 | City of Cape Town | Scottsdene | Scottsdene WWTP | 1 | Joubert Tulleken<br>Nicol Mostert | Wardi Trautmann | 0825693978 | YES | No major problems<br>Perfect example of well operated pump station |
| 6 | 21/09/2010 | City of Cape Town | Fisantekraal | New station | 1 | Joubert Tulleken<br>Nicol Mostert | Wardi Trautmann | 0825693978 | YES/ FOLLOW UP | Before station was in operation<br>Odour control system<br>Newest technology |
| 7 | 29/10/2010 | City of Cape Town | Blomtuin | Blomtuin Depot | 1 | Nicol Mostert | Albertus Klerns | 0219196662 | YES | |
| 8 | 18/10/2010 | Breede Rivier Vallei | Worcester | Worcester WWTP | 1 | Joubert Tulleken | Jaco Steyn | jsteyn@bvm.gov.za | YES | |
| 9 | 18/10/2010 | Worcester | Worcester | Avian Park | 1 | Joubert Tulleken | Jaco Steyn | jsteyn@bvm.gov.za | YES | Foreign objects in system |
| 10 | 18/10/2010 | Worcester | Worcester | Zweletemba | 2 | Joubert Tulleken | Jaco Steyn | jsteyn@bvm.gov.za | YES | Foreign objects in system, Removed pump for inspection |
| 11 | 28/03/2011 | Overstrand | Hermanus | Peach House | 0.5 | Joubert Tulleken<br>Mark Hoppe<br>JB Scheepers | De Wet Nel | 0825651898 | YES | Most houses have septic tanks<br>Relatively clean sewage |
| 12 | 28/03/2011 | Overstrand | Hermanus | Zwelihle Sport | 0.25 | Joubert Tulleken | De Wet Nel | 0825651898 | YES | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Mark Hoppe<br>JB Scheepers | | | | |
| 13 | 28/03/2011 | Overstrand | Hermanus | WWTP Main | 0.5 | Joubert Tulleken<br>Mark Hoppe<br>JB Scheepers | De Wet Nel | 0825651898 | YES | Most houses have septic tanks<br>Relatively clean sewage |
| 14 | 28/03/2011 | Overstrand | Sandbaai | Sandbaai PS1 | 0.25 | Joubert Tulleken<br>Mark Hoppe<br>JB Scheepers | De Wet Nel | 0825651898 | YES | Overflow into sea |
| 15 | 28/03/2011 | Overstrand | Onrus | Onrus Main | 0.5 | Joubert Tulleken<br>Mark Hoppe<br>JB Scheepers | De Wet Nel | 0825651898 | YES | Many pumps to decrease workload of pumps |
| 16 | 28/03/2011 | Overstrand | Onrus | Onrus Rome | 0.25 | Joubert Tulleken<br>Mark Hoppe<br>JB Scheepers | De Wet Nel | 0825651898 | YES | Generator is hidden away, limited eyesore |
| 17 | 28/03/2011 | Overstrand | Hawston | Hawston WWTP | 0.5 | Joubert Tulleken<br>Mark Hoppe<br>JB Scheepers | De Wet Nel | 0825651898 | YES | Developed a secondary screen |
| 18 | 28/03/2011 | Overstrand | Hermanus | Hermanus PS4 | 0.5 | Joubert Tulleken<br>Mark Hoppe<br>JB Scheepers | De Wet Nel | 0825651898 | YES | Fats from restaurants are problematic |
| 19 | 28/03/2011 | Overstrand | Hermanus | Mosselrivier PS | 0.25 | Joubert Tulleken<br>Mark Hoppe<br>JB Scheepers | De Wet Nel | 0825651898 | YES | |
| 20 | 21/04/2011 | CTIA | Cape Town | CTIA Sewage Disposal | 2 | Joubert Tulleken<br>Mark Hoppe<br>JB Scheepers | Nick Hanson | 0798985095 | YES | Macerator |

# *Appendix E Practical Implementation, Lab Experiment Drawings and Photos*

Design of circular screening basket used in practice is presented below. The basket has a hinged bottom to help with cleaning.




This same type of screening basket design as illustrated above is implemented at a Genadendal pump station as illustrated below.

Setup of laboratory experiment

Samples being dried for two weeks

# *Appendix F DST Program*